MAY 1951

Chemical Engineering Progress

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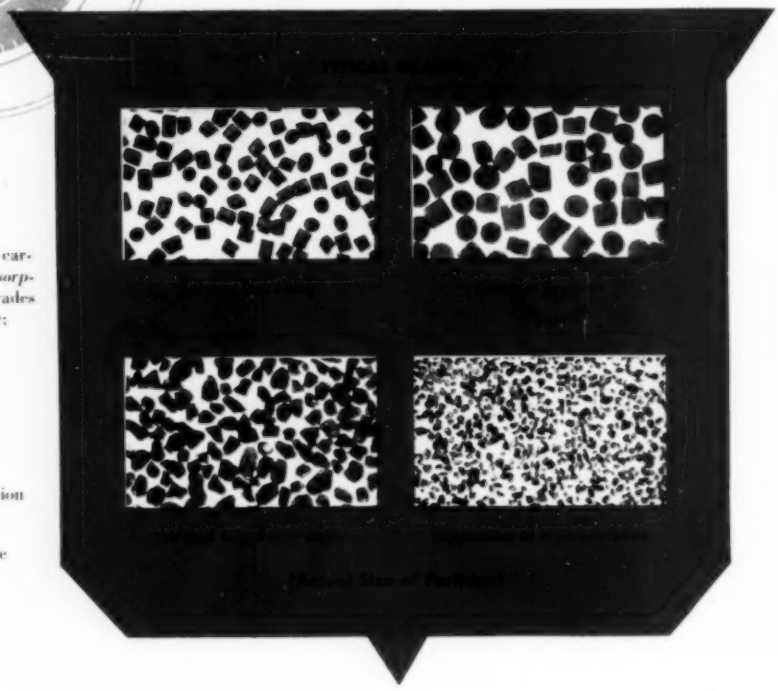

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Volume 47
Number 5

Chemical Engineering Progress

MAY
1951

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Published monthly by American Institute of Chemical Engineers, at 15 North Seventh Street, Philadelphia 6, Pennsylvania. Editorial and Advertising Offices, 120 East 41st Street, New York 17, N. Y. Communications should be sent to the Editor. Statements and opinions in *Chemical Engineering Progress* are those of the contributors, and the American Institute of Chemical Engineers assumes no responsibility for them. Subscriptions: U. S. and possessions, $6.00; Canada, $6.50; Pan-American Union, $7.50; Other Foreign, $8.00. Single copies of *Chemical Engineering Progress* older than one year cost $1.00 a copy; others are 75 cents. Entered as second class matter December 9, 1946, at the Post Office at Philadelphia, Pennsylvania, under the Act of August 24, 1912. Copyright 1951 by American Institute of Chemical Engineers. Member of Audit Bureau of Circulation. *Chemical Engineering Progress* is indexed regularly by Engineering Index, Incorporated.

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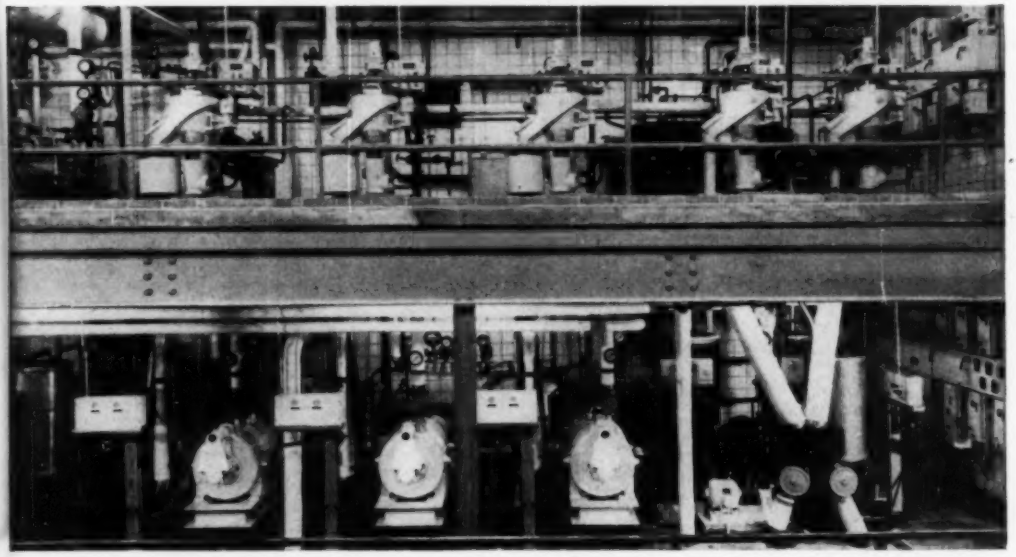

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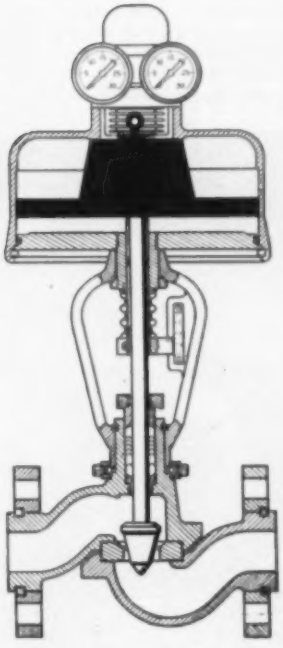

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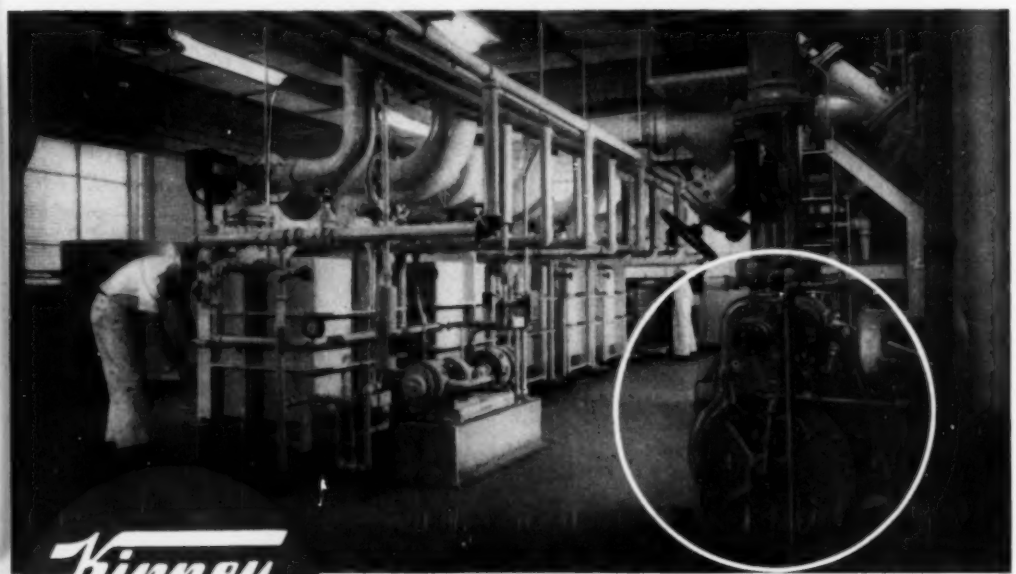

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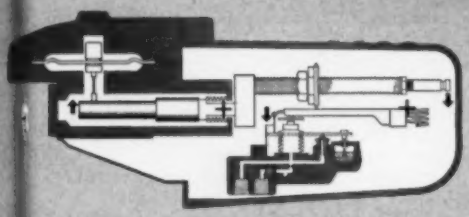

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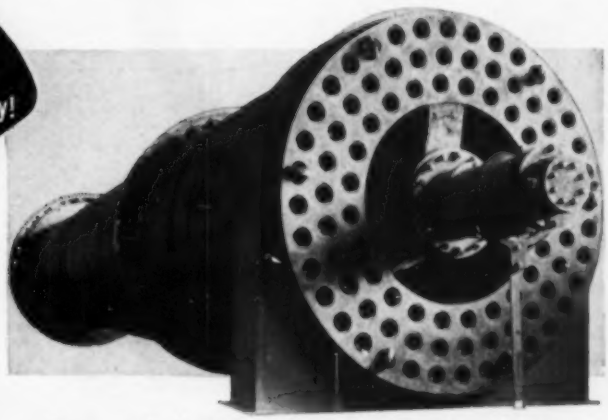

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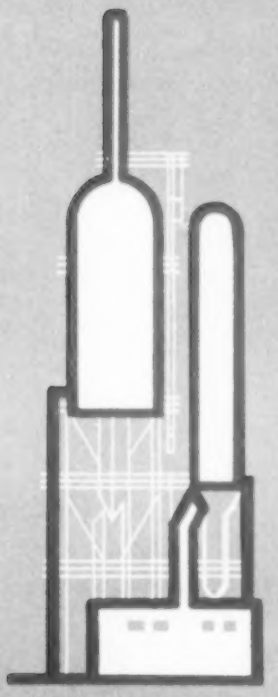

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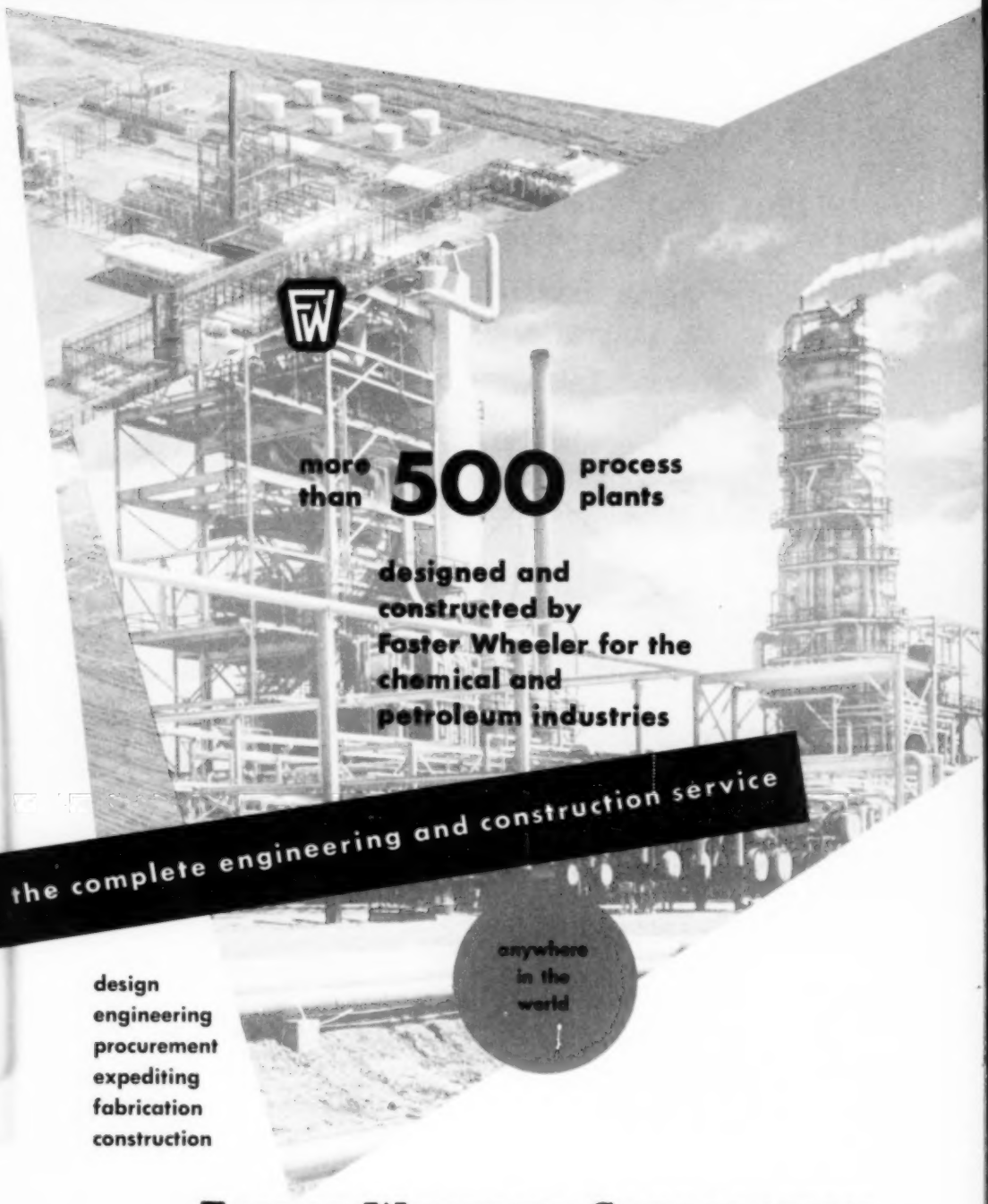

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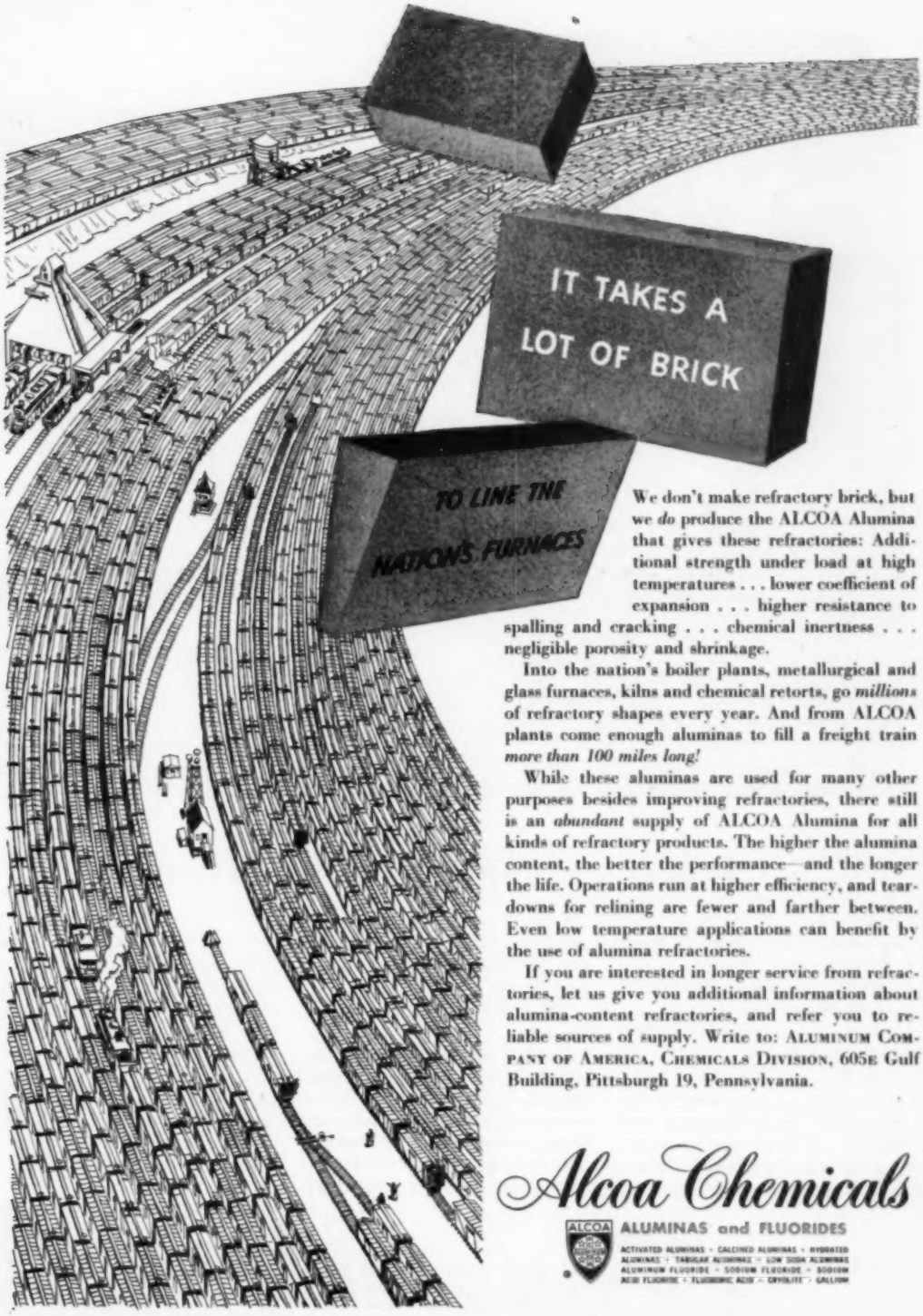

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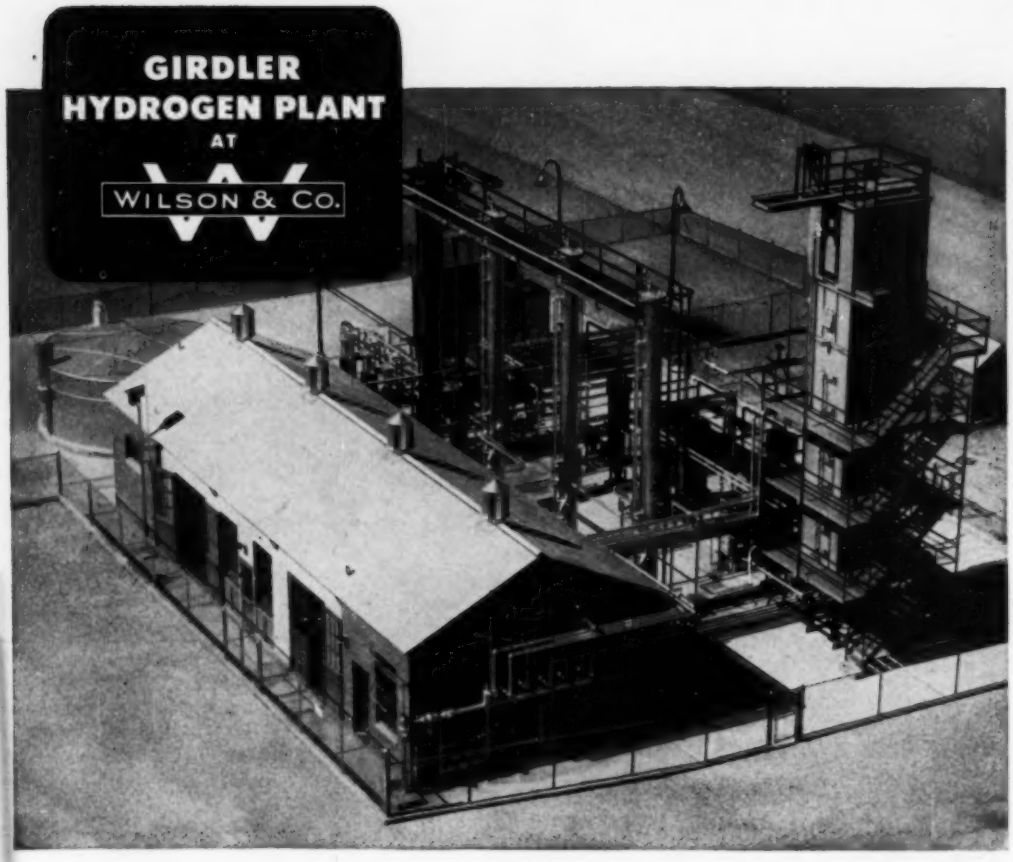

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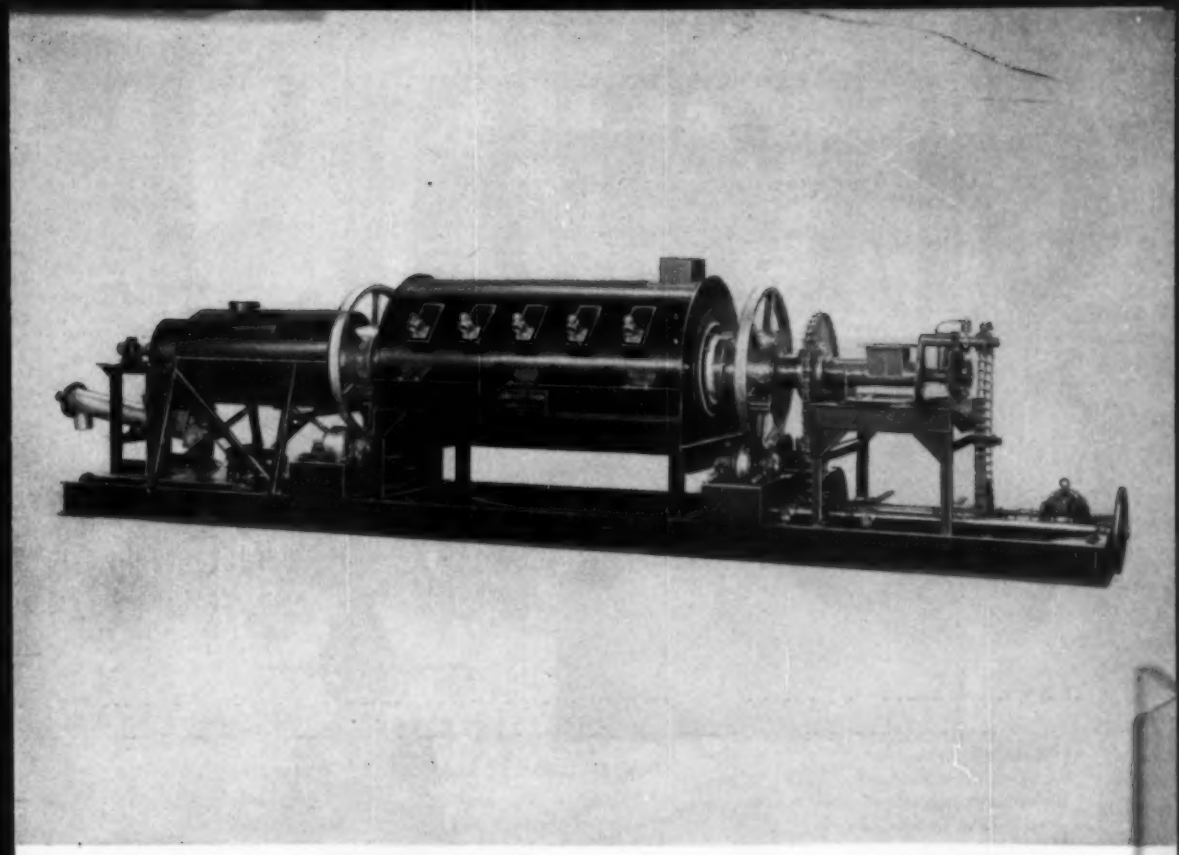

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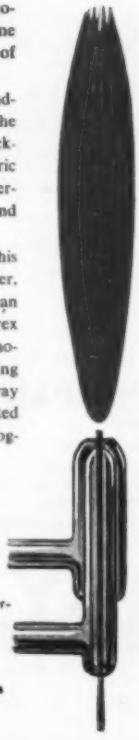

Illustration at right shows atomizer-burner actual size.

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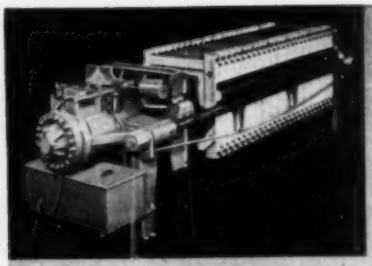

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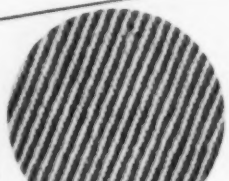

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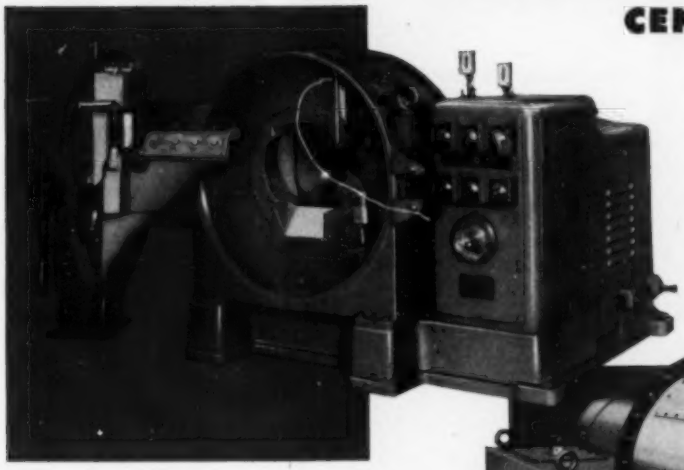

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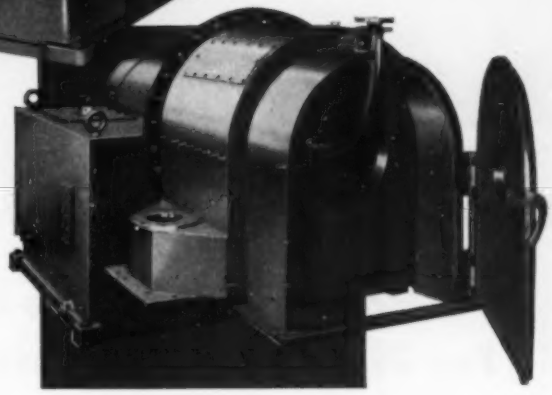

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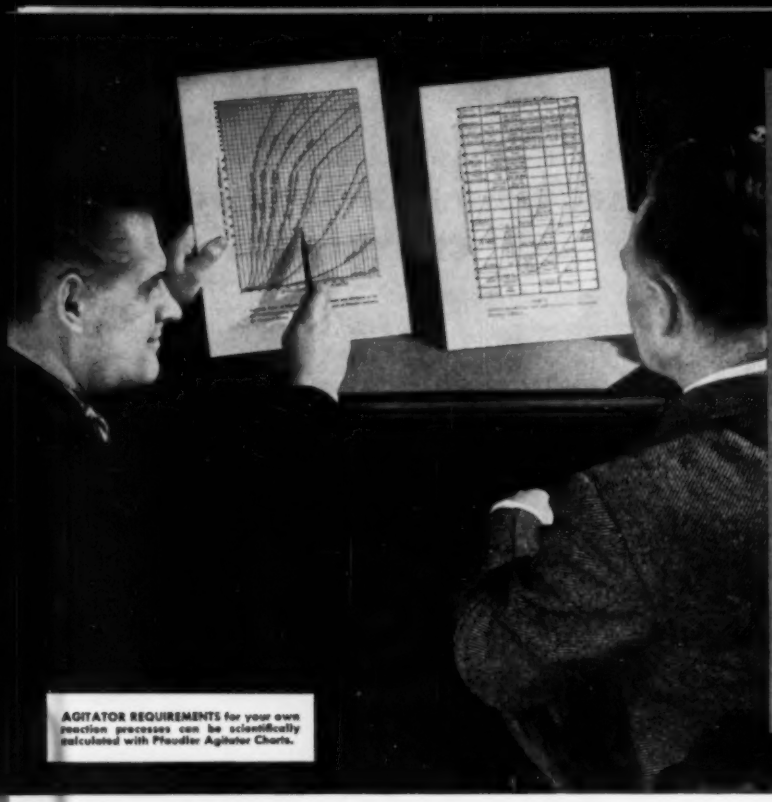

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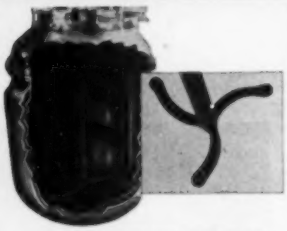

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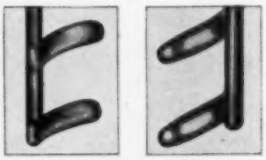

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OPINION AND COMMENT

MINIMIZING PERSONNEL OBSOLESCENCE

EDITOR'S NOTE

An experiment in adult education for technical men by the Humble Oil & Refining Co. came to the Editor's attention several years ago. This pioneering venture has proved itself and we have persuaded one of the men responsible for the success of this experiment to write here about it. H. Dayton Wilde is manager of the technical and research division, refining department.

ONE reason for the pre-eminence of American chemical and petroleum industries is that these industries do not hesitate to abandon and junk a perfectly good processing unit and replace it with a new unit that makes a new and better product or the same product more efficiently. Their research and technological staffs are constantly engaged in devising new or improved processes to take the place of existing ones. But technical men, as well as machines and equipment, can become obsolescent. Such phenomenally rapid progress is being made in science and engineering that unless technical organizations in industry maintain contacts that can keep them abreast with the new developments useful to them they can soon become woefully out of date.

One way of minimizing this obsolescence of technical men is for the company to select men from its technical staffs and arrange for them to take advanced courses at near-by educational institutions as part-time students or to send them away to universities on a full-time basis. This, in effect, is sending the men to school.

For the past five years the refining department of Humble Oil & Refining Co. has been doing the opposite, that is, bringing the school to its technical men. During these five years 23 eminent professors who are making the advances in their respective fields have come to Humble's Baytown refinery to teach such courses as the Nature of the Chemical Bond, Transference of Processes from Small to Large Scale, Theories of Organic Reactions, Chemical Engineering Thermodynamics, Emulsions, Thermodynamics of Nonelectrolytic Solutions, Catalysis, Applied Kinetics, Spectroscopy and Statistical Thermodynamics, and Adsorption and Surface Phenomena, to members of the technical service and research development staffs.

These courses do not consist of two or three lectures before large audiences in which the listeners can absorb as much or as little information as they desire. They are intensive courses lasting two or three weeks and each is the equivalent of a semester of a university graduate course. The classes are purposely kept small, with a maximum enrollment of 16, to provide an atmosphere of informality and close personal association with the professor. The students are relieved of all regular duties and devote their entire time to classroom work. The course content and manner of presentation are left to the judgment of the professor. In the majority of cases the professor gives a lecture lasting one or two hours in the morning and one of similar length in the afternoon. During the remainder of the normal working day the students work assigned problems and have conferences with the professor. The evenings are devoted to homework, assigned problems and reading. It is an arduous period for the students since they spend some 12 to 15 hours a day on this work.

A comprehensive examination concludes each course and the professor may give quizzes as the course progresses. The professors also grade the students on their work. The examination and grades provide an incentive for the students to do their best and foster a spirit of friendly competition.

The students for a course are selected from among those who have expressed a desire to take it. For some of the courses the demand has been so great that in these cases the professors repeated them another year. Each year about 80 to 90 per cent of the technical employees volunteer to take these courses, and although some employees take courses more frequently than others, on the average those desiring to take a course are able to do so every three years.

Including the professors' honorariums and expenses and the time of students for the duration of the courses, the cost of the courses is returned many times over. The technical staffs are kept abreast of the latest developments in their fields by the men themselves who are making the advances. Students are inspired by the professors and are eager to apply their new-found knowledge to their regular work. The professors get direct and first-hand information on industrial problems and accomplishments. They are then able to carry back to the college classrooms a better idea of what students need to equip themselves for careers in industry. The Humble Lectures in Science are no longer considered an experiment and the company management is convinced that they provide an effective means of minimizing obsolescence of its technical personnel.

H. Dayton Wilde

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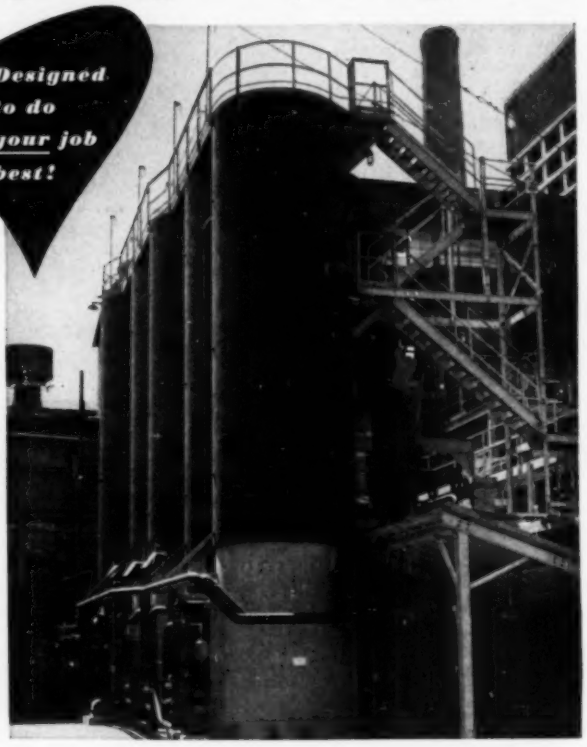

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The climate of the chemical industry "has bred some of the best managerial brains in the U. S.," so said Fortune last year in an editorial look at the chemical industry. Its editors were startled by what they saw, and in that March, 1950 issue said, "chemicals must now be considered the premier industry of the U. S. Its rise has been recent, precipitous and largely unnoticed. For most of the first half of the century, the title was held by the automobile industry." What concerns us here about the Fortune statement is the claim about managerial brains. If the chemical industry is to continue to develop leaders, attention must be paid to managerial talent, and companies must encourage its growth. Correlatively, future managers must study thoughtfully, in the sure knowledge of future succession, the characteristics of successful managers.

CHAPLIN TYLER

Du Pont Company, Wilmington, Delaware

ARE YOU OF EXECUTIVE CALIBER?

AT least three fifths of the American Institute of Chemical Engineers' Active membership are engaged primarily in some phase of managerial activity, ranging from group leadership to top executive responsibility.

Our future successors, the Junior members, have an even greater opportunity for satisfying careers in management. They are better trained in the basic sciences, have a better grasp of the humanities, and have broader scope for service in the industrial, academic, and public service fields.

An orthodox approach to the question, "Are you of Executive Caliber?" would involve much the same procedure as is used in research in the natural sciences, namely, (1) gathering of pertinent basic data, (2) organization of the data into a working hypothesis, and (3) application or testing of the hypothesis or assumed principles in relation to specific cases.

However, my own approach to this question is unorthodox. Rather than attempt an exhaustive sampling of the opinions of others, I have relied on my own personal observations. What I did was to list the names of executives with whom I have worked closely at various times over a period of 30 years. In the list were educators and editors as well as line executives and staff executives in industry. Included were young men on their way up as well as "old timers." From this list I selected those who seemed outstanding in capability, that is, as capable, taken as a group, as one might find anywhere. I then posed for myself this question: *What broad characteristics do these executives have in common?* What I sought were broad characteristics, because if one considers specific narrow traits, the main factors tend to become obscured in a maze of apparent contradictions. The broad characteristics as I view them are three in number:

(1) Energy or Drive.—This characteristic is manifest by great capacity for work, coupled with constructive direction of personal effort. One is impressed that such drive is directed at achieving results for the organization rather than primarily for self. Furthermore, this manifestation of energy is infective; it tends to impel or motivate effort in others.

An associate of mine terms the above characteristic "The will to do." I think this is a particularly apt description, because the capable executive is a determined person. He has a sense of direction, a plan, and a time-table. He is not only a good starter but also an equally good finisher.

A tendency toward laziness is so widespread among human beings that it probably should be considered normal. But in this respect it seems to me that the outstanding executive is not normal —he is abnormal. For example, not one of ten persons whom I would rate as top-grade executives seems to be happy unless engaged in some demanding situation. On the other hand, many I would rate as mediocre obviously do not push themselves.

The hope of monetary rewards or of broadened power may not be the primary incentive motivating the top-grade executive. The ten individuals referred to previously seem to be motivated by something else. Their philosophy of life is to give the job all they have. Material rewards and better position then follow as a matter of course.

(2) Effective Intelligence.—Because the executive spends so much time working with people, there is a tendency to overlook his role as a thinker. Actually the proper sequence in executive effort is thought followed by action. In spite of the staff assistance which an executive must have, a point is reached in every situation where the executive finds himself alone, figuratively speaking. He must "think the problem through" which means (a)

defining the problem, (b) resolving it, and (c) deciding on a practical course of action.

The person of effective intelligence possesses more than intellect. Usually he has an inquiring mind, continually seeks better ways and means of doing things, and has ability to express ideas clearly and fluently. He is intellectually honest, and he thinks straight. Although decisiveness is a mark of the good executive, one may be decisive and yet be a poor executive. Sound decisions are based on sound reasoning, i.e., the result of practical application of one's mental ability.

A large part of executive effort is expended in solving problems, i.e., tasks other than administrative routine. In solving problems, the top-grade executive is particularly wary of high-spot or superficial investigation. Thoroughness is the watchword, even at the expense of much valuable time. As one executive said to me, "Given sufficient data, a problem tends to solve itself; my mind must be saturated with facts before the right answer becomes apparent."

Many, if not most executive problems are of a recurrent type, though differing in their particulars. The good executive therefore tries to rationalize much of his thinking by developing formulas, even though these formulas may not be wholly quantitative. Examples of such problems are found in the fields of plant location, investment, choice of research projects, market surveys, and pricing.

(3) Effective Relationships with People.—From the executive viewpoint, people fall into three groups—superiors, associates, and subordinates. But far from being conscious of rank, the man of executive caliber strives to have equally good working relationships with all three groups. With respect to superiors he takes orders and accepts constructive criticism without resentment; with respect to associates he is unstintingly collaborative; with respect to subordinates he strives to evoke cooperative effort rather than to impose authority. This last factor is sometimes called leadership ability.

Some observers are inclined to regard leadership ability as a distinct broad characteristic apart from effective relationships with people. I think there is support for this view, but nevertheless I prefer to integrate the two. It seems to me that the qualities that evoke cooperative effort are those identified with effective relationships with people. The good executive sets the standard of behavior. By showing himself sincere, honest, and cooperative in dealing with others he has no great difficulty in evoking a response in kind.

Reviewing once more my test of ten top-grade executives, I find effective relationships with people developed in high degree. All are approachable, and all are good listeners. They are masters of the art of leading by example rather than by precept. As a general said recently of the Korean campaign, a situation was so critical that top brass was needed in the front line. Situations like that occur in industry, as at times in negotiating with a labor union, or in appearing before a Congressional committee.

In making important assignments and in major realignments of organization, the top-grade executive is eager to give whatever help he can in getting the work started in the right direction. We hear a great deal about the importance of initiative, but lack of initiative probably is not as serious as lack of coordination. The good executive, according to my observation, is a good coordinator. Having lessened the likelihood of confusion, he knows that individual initiative can have ample play without causing undue friction. Conversely, I once knew an executive who seemed to take sadistic delight in setting one subordinate against another. According to him, that was the way to develop strong men; i.e., only the fittest survived. Ironically, it didn't work out that way. Not only did some strong men rebel and resign, but also the executive himself finally was fired.

This, in outline is a characterization of the person of executive caliber. I have purposely avoided any weighting of the three broad attributes, as this would seem pointless. The man of executive caliber, like a well-balanced team, operates as a total organism. None can say that one component is more important than another. All are essential.

If these broad characteristics are reasonably inclusive, they should be as useful in analyzing cases of executive failure as in indicating potential success. By "executive failure" is meant cases in which demotion has occurred for reasons other than physical disability, reorganization, or situational factors beyond the individual's control.

In five of ten cases taken at random, my observation leads me to conclude that the primary cause of failure was ineffective relationships with people. In three cases, lack of drive was primarily responsible. In the remaining two cases, there was primarily a lack of effective intelligence. In no case was failure due to all-around deficiency, and in no case was there any evidence of deterioration, i.e., none of the individuals concerned had undergone any notable change in character.

In retrospect, one might ask why these individuals were advanced in the first place. Apparently there was lack of appreciation by those responsible for the promotions of the importance of balance as a factor in executive success. There is undoubtedly a tendency to overlook or even "forgive" a deficiency with respect to one characteristic when the other two are present in high degree. The hope, or reasoning seems to be that the strong characteristics will compensate for the deficiency. This can be an appealing argument, but experience indicates that the risk involved is great.

It is apparent also that much difficulty can be avoided by careful early appraisal of individuals being considered for line promotion. We all know that most high-level promotions are made only after painstaking consideration. Why not adopt the same attitude toward promotions at all levels? I think we would if we had a good yardstick. But not uncommonly the seriousness of a poor initial selection does not show up for many years. This is particularly true in the large organization, where the junior executive is subject to so many checks and balances that it is literally difficult for him to commit a major blunder. However, as he moves up the line, the number of checks and balances decreases. Executive weaknesses, previously obscured, begin to show up. The result is arrested progress, or in extreme cases, demotion.

In conclusion, suppose we again face the question, "Are You of Executive Caliber?" Clues to the answer probably lie in your own experience: For example, do people look to you to get things done? Are you in demand to head committees? Or do you like to sit tight and let the other fellow carry the ball? Are you called upon frequently to analyze tough problems, or are you merely asked to contribute data? Have you contributed in some substantial way to the advancement of your business, such as the formulation of better policies, rationalization of operations, or ideas that have matured into new or improved products? Do you enjoy working with people, or are you happier when left alone with a problem? Do you jump (almost literally) at the chance to give an associate a lift, and do others jump at the chance to give you a lift? In brief, do you have the will to do; do you think straight; and do your actions evoke cooperative effort?

Acknowledgment

The author wishes to thank W. R. G. Bender, manager of personnel research, service department, Du Pont Co., for his helpful review of various drafts of this paper.

(*Presented at Minneapolis (Minn.) Meeting.*)

HOW IS YOUR SALARY DETERMINED?

STANLEY P. FARWELL

Business Research Corporation, Chicago, Illinois

HOW Is Your Salary Determined?" The most obvious answer to this question would be, "I don't know," and it would be perfectly correct because the correct answer depends on the policies and practices of the companies in which you are employed.

In the so-called process industries there are a number of concerns which are well known for their progressive industrial relations and salary administration policies and practices. Also among the companies there must be some which are not so advanced and in which a man's salary is arrived at by policies and influences which are not quite up to date. I shall in this article in the main, try to outline for you the policies and methods for salary determination which are typical of the most advanced practice in American industry.

For convenience a hypothetical corporation, the XYZ company can be used. This company is in a process industry. It has a general office in Chicago and a number of plants scattered around the country.

At its general office is its president and a number of vice-presidents, in charge of the usual fields of activity. One of these vice-presidents has charge of industrial relations and he has a well-staffed department, including a wage and salary administrator whose job it is to administer wages and salaries up to a certain level. I shall come back to him later in discussing how salaries are fixed.

The XYZ company also has a Salary Committee made up of vice-presidents, which formulates salary policies for approval by the president and passes on recommendations for increases in the pay of positions up to a certain level, above which the president has this responsibility.

To round out the roster of those involved in determining wages and salaries I should mention that in each plant there is a personnel manager, who usually reports directly to the plant manager but is under the functional supervision of the vice-president in charge of industrial relations at the general office.

In outline the principal features of a modern salary administration plan such as installed in the XYZ company are as follows: The company will, of course, have made full use of job evaluation to determine the relative importance of all positions in its service which it chooses to include in the evaluation. The company several years ago evaluated all of its "hourly rated" plant and operating jobs and then all of its salaried clerical, office, and technical jobs up to a certain level. And it has just completed an evaluation of all its "managerial" positions, which classification includes those of a supervisory, administrative, executive, staff, professional, or technical nature up to a high level.

The technique of evaluating managerial positions is a comparatively recent development. The plan developed by the Business Research Corp. has now been successfully applied in 15 substantial companies so it is well out of the pilot-run stage. With it even vice-presidential positions have been accurately evaluated.

Since job evaluation plays so important a part in determining wages, salaries and compensation of many, I shall define it, tell why it is needed, and touch the high spots of this technique.

Job evaluation is the process of analyzing and grading jobs or positions so as to establish pay rates which fairly compensate the degree of skill, effort, experience, and responsibility required for each job.

Wages or salaries paid according to rates established through this process will be in correct relation to each other for all levels covered. In addition, it will be possible through having adequate job descriptions to make more accurate comparisons with rates paid in the industry or community for similar work.

An excellent comment on the need for job evaluation is found in the job evaluation manual issued by a large chemical company in cooperation with its union.

> The determination of how much one job is worth as compared to another—rather, as compared to several thousand others—can no longer be left to guesswork or rule of thumb. To do so could mean only discrimination and general sloppiness in the wage structure. It would mean also that the union and the company would be faced with the superhuman task of bargaining separately over the wages of almost every man in the plant. It would mean almost as many wage rates as workers. In short, it would mean a situation in which no one would ever be sure he knew anything about anything.

From my close acquaintance with many kinds of establishments, I cannot help but conclude that in numerous cases their wage structures, like Topsy, "just growed." The wage rates paid at any particular time are often the result of many different influences and forces such as:

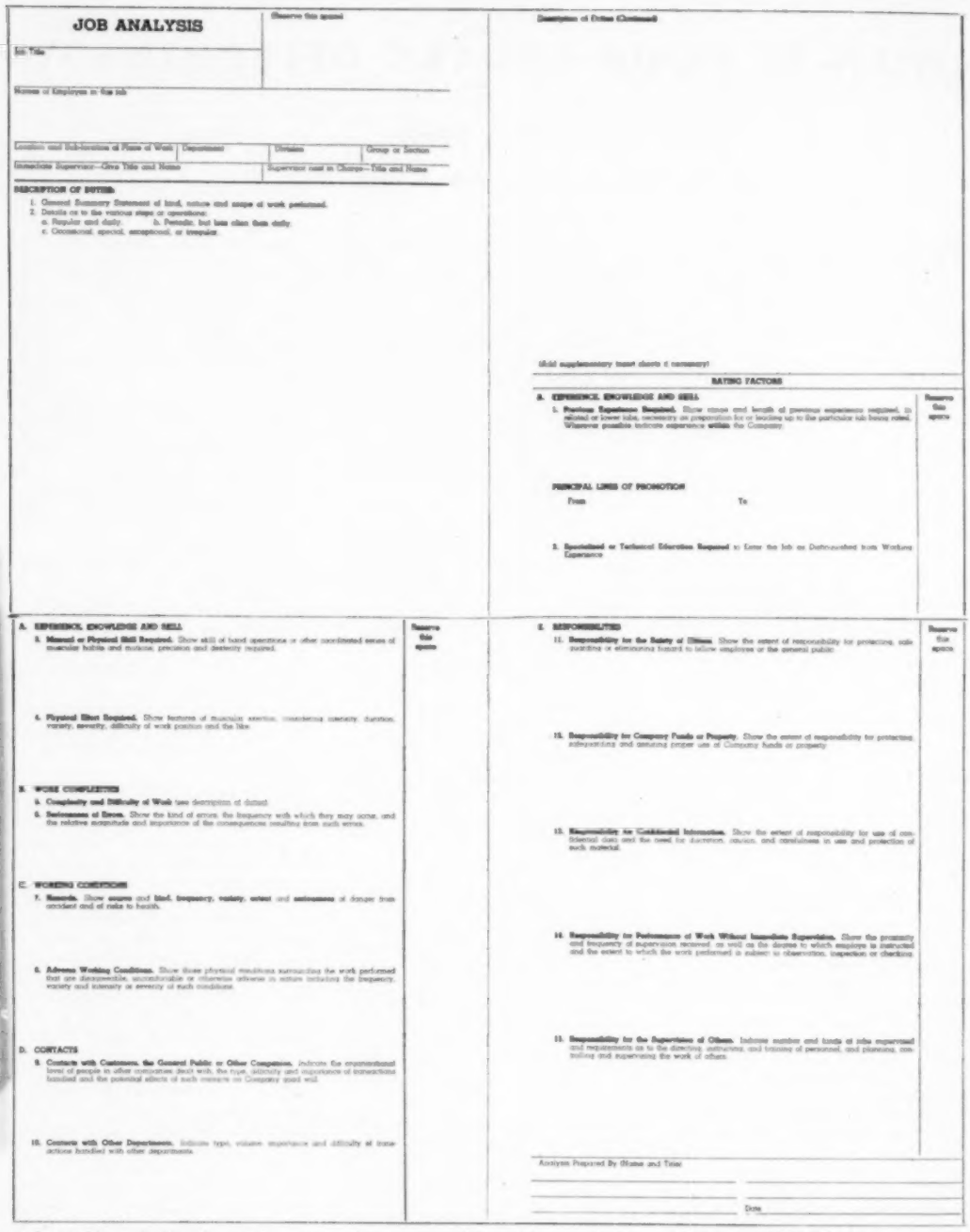
Over- or underestimating the requirements of a job.
Paying according to the man in the job; not for the job itself.
Favoritism, or the opposite.
Whether an executive in charge of a particular group of employes is one who "goes to the front" for his men or holds back.
Wages rates in the industry.
Pressure of supply and demand in the labor market.
Seniority.
Union pressure through collective bargaining.
Cost of living.

Some of these influences are normal and affect the wage rates of all or most of the jobs concerned, but there are others which operate to create more or less serious and unnecessary inequities in wage rates.

It is well known that such internal inequities *can* and *do* cause more bad feeling than the fact that some other company may be paying higher rates. If Bill Smith thinks he is doing just as important a job as Sam Jones who works alongside of him, but finds that Sam gets 10 cents an hour more than he does, he has a feeling of injustice which rankles and causes discontent. Obviously, it is important to remove all such inequities and misunderstandings as far as possible, both in the case of rank-and-file jobs and managerial positions.

Now to outline some of the techniques used in job evaluation. Job evaluation always starts with a careful analysis and statement of the duties and responsibilities of the position and in most cases specifications as to the education, experience, and other qualifications required for a person filling the position. This is "job analysis" and the completed statement is called a job or position description. Sometimes it is termed a "specification" rather than a "description."

These job descriptions are so written as to follow the pattern of the several "factors" of the rating scale which is



JOB ANALYSIS

Job Title

Reserve this space

Names of Employees in the Job

Location and Sub-Location of Place of Work | Department | Division | Group or Section

Immediate Supervisor—Give Title and Name | Supervisor next in Charge—Title and Name

DESCRIPTION OF DUTIES

1. General Summary Statement of kind, nature and scope of work performed.
2. Details as to the various steps or operations:
   a. Regular and daily b. Periodic, but less often than daily.
   c. Occasional, special, exceptional, or irregular.

Description of Duties (Continued)

(Add supplementary insert sheets if necessary)

RATING FACTORS

A. EXPERIENCE, KNOWLEDGE AND SKILL

Reserve this space

1. **Previous Experience Required.** Show nature and length of previous experience required, in related or lower jobs, necessary as preparation for or leading up to the particular job being rated. Wherever possible indicate experience within the Company.

PRINCIPAL LINES OF PROMOTION

From To

3. **Specialized or Technical Education Required** to Enter the Job as Distinguished from Working Experience

A. EXPERIENCE, KNOWLEDGE AND SKILL

Reserve this space

4. **Manual or Physical Skill Required.** Show skill of hand operations or other coordinated senses of muscular habits and motions; precision and dexterity required.

6. **Physical Effort Required.** Show features of muscular exertion, monotonous intensity, duration, variety, severity, difficulty of work position and the like.

B. WORK COMPLEXITIES

5. **Complexity and Difficulty of Work** (see description of duties).

6. **Seriousness of Errors.** Show the kind of errors, the frequency with which they may occur, and the relative magnitude and importance of the consequences resulting from such errors.

C. WORKING CONDITIONS

7. **Hazards.** Show **source** and **kind, frequency, variety, extent** and **seriousness** of danger from accident and of risks to health.

8. **Adverse Working Conditions.** Show those physical conditions surrounding the work performed that are disagreeable, uncomfortable or otherwise adverse in nature including the frequency, variety and intensity or severity of such conditions.

D. CONTACTS

9. **Contacts with Customers, the General Public or Other Companies.** Indicate the organizational level of people in other companies dealt with, the type, difficulty and importance of transactions handled and the potential effects of such contacts on Company good will.

10. **Contacts with Other Departments.** Indicate type, relative importance and difficulty of transactions handled with other departments.

E. RESPONSIBILITIES

Reserve this space

11. **Responsibility for the Safety of Others.** Show the extent of responsibility for protecting, safeguarding or eliminating hazard to fellow employees or the general public.

12. **Responsibility for Company Funds or Property.** Show the extent of responsibility for protection, safeguarding and assuring proper use of Company funds or property.

13. **Responsibility for Confidential Information.** Show the extent of responsibility for use of confidential data and the need for discretion, caution, and carefulness in use and protection of such material.

14. **Responsibility for Performance of Work Without Immediate Supervision.** Show the proximity and frequency of supervision received as well as the degree to which employee is instructed and the extent to which the work performed is subject to observation, inspection or checking.

15. **Responsibility for the Supervision of Others.** Indicate number and kinds of jobs supervised and requirements as to the directing, instructing, and training of personnel, and planning, controlling and supervising the work of others.

Analysis Prepared By (Name and Title)

Date

to be used in evaluating the position. As an illustration, the rating scale used by the Business Research Corp. for clerical and office positions has 15 factors. A typical job analysis form is shown on this page.

The managerial position evaluation scale has only nine factors, covering responsibilities for the following:

Programs, Projects, or Operations
Supervision of Personnel
Employee Relations
Customer or Public Contacts
Internal Contacts
Investigations or Fact-Finding
Planning, Scheduling, or Forecasting
Establishing Standards
Gain or Loss

With carefully prepared and approved position descriptions in hand, the next step is to rate them. This is usually done by a thoroughly qualified committee of company executives, with consultants sitting in. Under our rating plans, the Rating Committee assigns each position a certain number of "points" for each factor, and the sum of these points for all the factors gives the over-all point-rating for the position, which fixes the relative ranking of the position with respect to all other positions so evaluated.

A chart is then prepared on which each position is represented by a point determined by the point-rating (abscissa) and salary (ordinate). These points form a "scatter" diagram. The next step is to calculate the "line of regression" (more popularly, "trend line") to fit the array of points, and plot it on the chart.

Having plotted the trend line, use is made of all available information as to what salaries are paid for comparable positions in the area or industry and the slope or level of the trend line may be changed to meet competitive conditions.

An accompanying graph shows such a typical structure. It consists of a number of "salary grades," each of which has a salary range from minimum to maximum. All positions fall into one or another of these grades. When this structure is approved by top management, it establishes the framework by which all salaries covered by it are administered—a process outlined by the following typical case.

Let us assume the case of a chemical engineer working in one of the plants of the XYZ company in either development or production work. The position has been covered by job evaluation and a salary range established for it which fairly represents its importance with respect to all other positions evaluated.

The salary received at any time depends upon his performance in the position as registered in the minds of the people he works for. It may be that this impression has not been reached through any formal process or it may have been crystallized through a merit-rating process such as is being increasingly adopted by progressive companies.

In this process two or three people who are in the line of authority above him would record their impressions on a scale covering the quality of his work, its quantity, his dependability and other important attributes, which together give a good indication of the quality of his work. Such merit ratings would be made yearly.

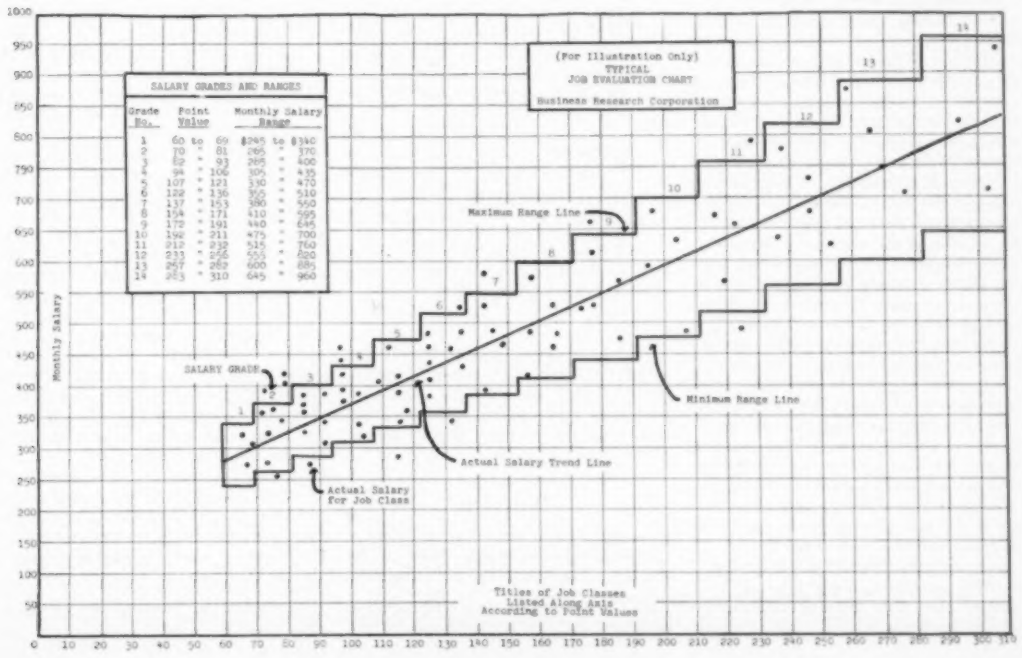
Usually salaries come up for review either on the anniversary of a person's employment with the company or yearly at a certain time for all employes. Either practice is good. When such a review is made, immediate supervisors consider situations and may make recommendations to the head of the department for an increase within the range set for a position. The department head then turns in his recommendations to the plant manager, who calls the plant's personnel manager into consultation to get his advice, both as to the merits of the recommendation and as to whether they conform to the company's salary administration policy. From there on the handling of increases depends on whether the company's salary administration is centralized or decentralized.

Some well-known companies are highly centralized in this respect and increases must receive consideration by top officials or the salary committee at the main office. In other companies the plant manager has authority to grant increases up to a certain level in the organization, provided that they are within the established ranges and he keeps the average pay for all positions around a certain level. Usually where the plant manager has such authority he must refer proposed increases which are out of the ordinary to the general office. I personally favor the decentralized plan.

One of the questions frequently asked of me is "Can a man expect an average percentage increase each year?" This must be answered in several steps.

If you happen to occupy a rank-and-file position in one of the lower salary grades you probably would receive automatic increases at regular intervals of six months or a year provided you were doing an acceptable grade of work. Through this process you might receive a total increase in salary of 25% or 30% in two or three years.

If you were in what I might call a


(For Illustration Only)
TYPICAL
JOB EVALUATION CHART
Business Research Corporation
SALARY GRADES AND RANGES
Grade No. | Point Value | Monthly Salary Range
1 60 to 69 $295 to $340
2 70 " 81 295 " 370
3 82 " 93 295 " 400
4 94 " 106 305 " 435
5 107 " 121 330 " 470
6 122 " 136 355 " 510
7 137 " 153 380 " 550
8 154 " 171 410 " 595
9 172 " 191 440 " 646
10 192 " 211 475 " 700
11 212 " 232 515 " 760
12 233 " 256 555 " 820
13 257 " 282 600 " 885
14 283 " 310 645 " 960
Maximum Range Line
Minimum Range Line
SALARY GRADE
Actual Salary Trend Line
Actual Salary for Job Class
Monthly Salary
Titles of Job Classes Listed Along Axis According to Point Value

middle-grade position in the rank-and-file group you might be advanced more or less automatically to the median of the range for your position. Subsequent increases would be based upon a more careful appraisal of the quality of work you are doing. Such increases are known as "merit" increases. After several of these your salary would finally reach the maximum for your position, which would be around 30 per cent above the minimum. This whole process might take four or five years.

In the case of higher positions, especially those in the managerial group, increases are not automatic. Under proper salary administration each would be based on merit as determined by a careful appraisal of each man's performance. In the upper levels of an organization the salary ranges may be as much as 40 or 50 per cent and normal movement through them would take a length of time depending on the quality of the man's performance. Increases for top-level positions are usually determined by a salary committee and/or the president.

When an employee has reached the maximum salary set for his position further advancement salarywise in general depends upon promotion to a higher position. Of course, there are sometimes exceptions but it is becoming more and more generally recognized that there is a limit to what a position is worth to a company and that to break through maximums soon impairs the whole salary structure.

Modern salary administration requires that the salary structure both as to ranges for position and general level of the entire structure be under constant review to meet changing conditions both in the content of jobs and in general salary levels, which are affected by cost-of-living and other valid influences.

Salary administration of high quality requires the services of people who are expert in this field and as much stability as possible in the staff assigned to this important task. Proper maintenance of the salary structure also requires strong interest and support on the part of top management. In the progressive companies which have good salary administration this support has been present.

The most progressive companies have evolved sound salary policies which they have reduced to writing for the guidance of all concerned. This practice should be followed by all companies which want the best results.

Another question frequently put to me is, "Could a salary policy be stated in a few words—if so, what?"

A good statement of a salary policy certainly requires more than a few words. However, some of the criteria which consciously or unconsciously should be applied in the determination of a fair salary for any managerial position are the following:

1. The salary should be in line with those paid for positions of like difficulty and importance in the company.
2. The salary should be in line with those paid similar positions in the area or industry.
3. The salary should be sufficient to permit a standard of living appropriate to the position.
4. The salary should be such as will attract and hold good men.

Another question put to me is this: "Is the salary a man receives entirely a function of ability, length of service, luck, or ability to 'polish the apple?'" My answer to this question is piecemeal:

1. The more perfect a company's salary administration the more recognition is given to ability.
2. Length of service is recognized salarywise up to a certain point. Beyond that increases should not in general be given for length of service within a given position.
3. Luck sometimes plays a part in a man's advancement. Sometimes a man happens to be in the right place at the right time and he receives the favorable attention of the right people, whereas someone else equally able and as well qualified for promotion is not so strategically placed. Probably such factors will always have some influence but the probability is minimized in a company which has a good administration.
4. "Polishing the apple" is an old school-boy technique which is not entirely unknown in other circles and it sometimes gets results. This process does not get far with an alert executive, and the technique is quite apparent to the associates of the man who employs it and it does not raise him in their estimation.

If I have not been able to tell you specifically how *your* salary is determined, I have presented an outline of how it would be determined under the most modern salary administration policies and practices.

Discussion

Someone from the floor has asked a question on replacement charts. The question is answered by S. P. Farwell.

S. P. Farwell. You are all familiar with an ordinary organization chart which consists of a series of rectangles on different levels with lines connecting them. Some companies make use of what are sometimes termed replacement charts which look a good deal like an organization chart. In fact I have seen ordinary organization charts used for that purpose, only the different rectangles representing the positions had different colors placed on them, which indicated the opinion in which the men holding those positions were held by top management. These different colors would be such that let's say one color would mean, "this man is O.K., he is a comer and we are all set for filling the position above him." In another case, another color might indicate that "this man is not quite up to snuff. If his superior passes on he will not be ready for promotion." Still another color might mean "this man is unsuited for the work he is in and there is no possibility of his filling the job ahead of him."

That kind of a chart is a guide to executive action. First of all, it may indicate that certain people are in need of more education or more experience, or certain kinds of experience. Then the alert management sees to it that such a man, if he is worth the attention, does receive special treatment to qualify him for promotion.

If, however, the opinion is that a man is not worth such attention, then the management looks for a position to which he may be transferred and in which position he can do a good job and be satisfactory to himself as well as to the company.

One reason that kind of chart is being used these days is that it is so difficult in many instances to find people who are qualified for higher executive positions. This is an age of specialists. I have sat with the president of one company in particular, when he was trying to find men to promote to general management positions. We went all through the roster of his principal people who were departmentalized, and we couldn't find anybody who could be promoted to that particular executive position which was a good one. In a few cases this process led of necessity to employing men from outside. The practice of going outside when you have to, is good. A company cannot afford to stay inside all the time if it hasn't people ready for the promotion that is available. Of course, it is to its discredit sometimes that it hasn't such a qualified man lined up. Progressive companies are laying more and more emphasis on seeing to it that they do have good runners-up and qualified people in reserve to meet all reasonable eventualities.

(Presented at Minneapolis (Minn.) Meeting.)

THERMAL CONDUCTIVITY OF GASES

Measurement at High Pressure

J. M. LENOIR† and E. W. COMINGS

University of Illinois, Urbana, Illinois

An apparatus was constructed for measuring thermal conductivities of gases at high pressure to a precision of 1½ per cent at low values of thermal conductivity and of 3 per cent for high values of thermal conductivity. Pressure-thermal conductivity isotherms for nitrogen, methane, argon, hydrogen, helium, ethylene, and carbon dioxide were determined from 1 to 200 atm. Results with nitrogen agreed with the previous findings of Vargaftik (*18*), who measured values up to 90 atm. The correlation by Comings and Nathan (*2*), was found to give good agreement with the measured values except in the region near the critical state, where the correlation predicted low values.

THE design of high pressure equipment involving gases requires a knowledge of gas properties. Pressure-volume-temperature relations and the effect of pressure on viscosity are known to a considerable extent. In general, the effect of pressure on thermal conductivity had not been measured. Only a limited amount of data had previously been obtained at elevated pressure because of experimental difficulties. The relative change of thermal conductivity with pressure is of the same magnitude as that of viscosity, and may amount to several hundred per cent. For this reason thermal conductivity data are important in considering heat transfer at high pressure.

The change of thermal conductivity with pressure has been predicted theoretically by Enskog (*4*) and Chapman (*1*). Comings and Nathan (*2*) evaluated the constants in the Enskog equation for a number of gases and found that the thermal conductivity ratio for the various gases was comparable at corresponding states. These authors were able to make a generalized correlation of thermal conductivity ratio as a function of reduced pressure and reduced temperature.

The thermal conductivity of gases has been measured at atmospheric pressure by a number of investigators (*17*) who used some modification of the Schleiermacher (*13*) device, an apparatus consisting of an electrically heated wire centered inside a tube. A measured quantity of heat is caused to flow from the wire, through the test gas layer, to the surrounding walls of the tube, with wall and wire temperatures being measured. Corrections for radiation and heat flow along the wire to the ends of the apparatus are required and convection in the gas must be avoided.

When a fluid is confined between parallel walls a stabilizing effect occurs tending to prevent convection. This effect is inversely proportional to the cube of the distance between the walls, and a narrow space is required to prevent convection. Kraussold (*11*) examined the results of a number of investigators on heat transfer through stagnant gas layers and included results of his own on water and oils. These results in the main applied to annular spaces, both in vertical and horizontal positions, but some of the data on gases applied to horizontal gas layers. Kraussold expressed the actual heat transfer in terms of a fictitious thermal conductivity which included heat transfer by convection. The ratio of this apparent conductivity to the true conductivity was then found to be a function of the product of the Grashof

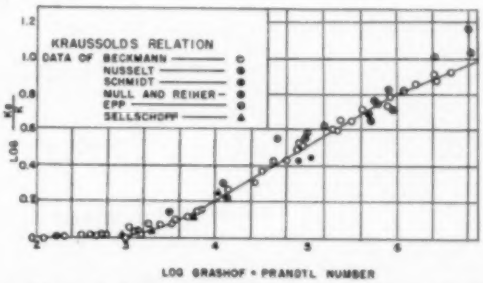


Fig. 1. Kraussolds correlation of ratio of apparent to true thermal conductivity for heat transfer across a layer of fluid.

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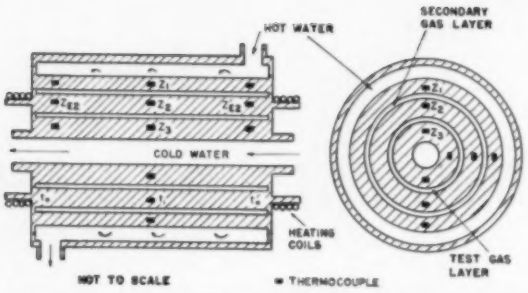

Fig. 2. Schematic arrangement of thermal conductivity apparatus showing relative position of thermocouples.

and Prandtl numbers, provided that this product was greater than 600. Below 600 the apparent and true conductivities were equal, and were independent of the Grashof and Prandtl number product. The function is shown graphically in Figure 1. The ratio of apparent to true conductivity at values of Pr.Gr. product below 10,000, appeared to be independent of whether the gas layer was vertical or horizontal, or of annular shape, and independent of the direction of temperature gradient. All the data were obtained at atmospheric pressure except that by Sellschopp (*15*). Kraussold's method of plotting Sellschopp's data was not rigorous, and the application of Kraussold's relation at high pressures on this basis cannot be accepted with assurance. The value of D in the Grashof number was the width of the gas layer. Schmidt and Milverton (*14*) studied heat transfer through various thicknesses of water and concluded that if the product of Grashof and Prandtl numbers was less than 1709 convection was absent.

Sellschopp measured thermal conductivity at high pressure using a modified Schleiermacher apparatus with a gas layer thickness of 0.010 in. The values he obtained at atmospheric pressure were 3% lower than other literature values. This was probably due to limitations in the apparatus design connected with establishing a uniform gas layer width and in measuring this width with sufficient accuracy. Sellschopp confined his study to carbon dioxide up to 90 atm. In the region of the critical state, from the Grashof and Prandtl numbers, the tendency for convection is very large. Fifteen measurements close to the critical were shown by Sellschopp to be invalid due to convection. The majority of his data was evidently taken under convection free circumstances, and the statements of others (*2, 18*) that all of Sellschopp's data are invalid because of convection are erroneous.

Using another type of Schleiermacher apparatus Vargaftik (*18*) obtained measurements on nitrogen and water vapor up to a pressure of 90 atm. He used a thickness of gas of 0.014 in. but because the nitrogen was in a state relatively far away from the critical state he was able to avoid convection. Vargaftik was unable to measure the thickness of his gas layer to a sufficient accuracy and found it necessary to calibrate his apparatus using accepted thermal conductivity values for air.

The difficulty of measuring thermal conductivities at high pressure lies in the increased tendency towards convection when the pressure is increased. An extremely thin gas layer is required. The fabrication of a precisely uniform thin gas width is a requirement of a Schleiermacher apparatus. This is difficult and for this reason the Schleiermacher, or direct method, was rejected and an indirect method was selected which does not require an exact knowledge of the gas layer thickness or the rate of heat transfer through it. This method requires calibration of the apparatus with gases of known thermal conductivity.

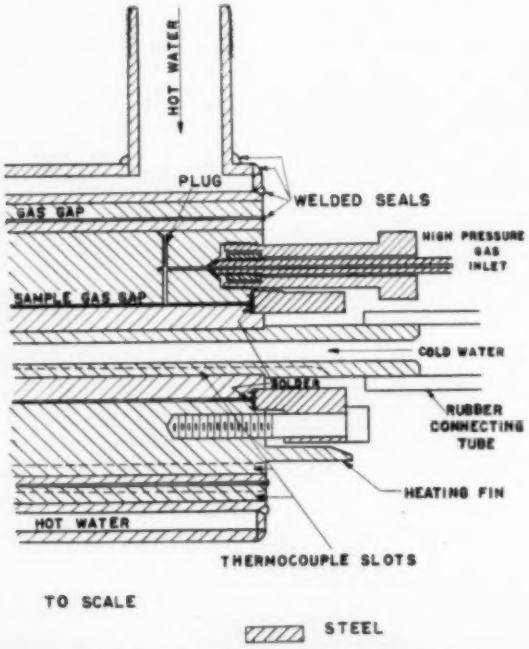

Fig. 3. Assembly drawing showing bomb end A.

Description of Apparatus

The apparatus was constructed of concentric steel tubes (SAE 1015) 30 in. in length. Figure 2 shows the basic principle of the design. Considering the end-section view the apparatus was made of four horizontal steel tubes each concentric with the other, and with annular gaps between them. Cold water was passed through the innermost tube; hot water, through the outermost annulus. Between the innermost tube and the next larger tube was the sample gas layer, 0.008 in. thick. Between the second and third tubes was a second annular gas layer 0.033 in. thick which was filled with nitrogen, methane, or helium at one atmosphere pressure. Temperatures were measured by thermocouples designated by the letter Z. The function of the second gas layer was to increase the thermal resistance between Z_1 and Z_2 to a magnitude equal to the thermal resistance between Z_3 and Z_4.

Heat flowed from the hot water, across the series of concentric steel tubes and gas layers, to the cold water. The central tube (thermocouple location Z_2) received heat by conduction through the gas layers surrounding it, and also by conduction through the metal seals at the ends of apparatus. These metal seals had a thermal conductivity of the order of 2000 times that of the gases, and tended to act as short circuits for the heat flow. By making the low pressure seal relatively small in area and the high pressure seal larger in area, an approximate balance of thermal resistances was obtained so that the end temperatures, t_0 and t_0' were approximately the same as the middle temperature, t_1. Metal fins were placed at both ends of this central tube with heating or cooling coils. By controlling the heat introduced in these coils, t_0 and t_0' were brought to the same temperature as t_1, to within 0.1° F. without difficulty. The middle temperature, t_1, was not sensitive to the end temperatures. With such thin gas layers and all metal construction the radial heat flow was large, of the order of 100 B.t.u./hr., which minimized the effect of end-temperature differences on the readings of the central thermocouple, Z_2.

It was desirable that the thickness of both gas layers be as uniform as possible. The surfaces were precision-honed to a mirror finish. The tubes were mounted inside one another by using shims at the ends. Uniformity of the gas layer thickness was checked by directing a light into the gas layer space at one end and noting the illuminated circle at the other end. Nonuniformity of the gas space anywhere along the length resulted in darkening of the circle along that side. This was corrected by springing the tube slightly.

An assembly drawing of the high pressure inlet end of the apparatus is shown in Figure 3. The other end consisted of the same arrangement except the pressure inlet connection was absent. Seven tubes were used. One served as a hot-water jacket. The other six were made into three tubes by press-fitting the larger over the smaller. This was done to permit construction of the thermocouple wells, which were ⅛-by ⅛-in. slots. Nine were 15 in. long, and six were 6 in. long. The long ones were used to measure temperatures in the middle of the apparatus where end effects have a minimum influence on temperature. The short ones were used to measure end temperatures. The press fit construction is denoted by a change in cross-hatching on Figure 3, and the thermocouple well locations are shown by the dotted lines. Three sets of thermocouples were used to measure the middle temperatures corresponding to the top, side, and bottom positions in the apparatus.

The extreme thinness of the gas layers in relation to the metal walls is shown on Figure 3. The sample gas layer had an inner radius of 0.653 in., the outer gas layer, an inner radius of 1.614 in. The walls were designed to withstand safely a sample gas pressure of 550 atm. The inner pressure wall was 0.40 in. thick: the outer pressure wall was 0.953 in. thick. The wall confining the outer gas layer was 0.35 in. thick. All these walls were made of two shells of steel, thus there was a discontinuity in each wall.

To ensure that the hot water would contact all of the outer surface, a helical coil was placed in the water jacket space to cause the water to flow in a spiral path between the turns of this coil and around the outside surface. Both the hot and cold water were pumped at high velocity through the apparatus. Water temperatures were maintained constant using large 40-gal. baths with stirrers and heaters, with Capital Chemical Co. thermoregulator controllers sensitive to 0.03° F.

The pressure of the test gas was measured by two 12-in. diameter Bourdon gages, one covering the range 40 to 1200 lb./sq.in. gage and the other, 1200 to 3000 lb./sq.in. gage. These gages were calibrated by a dead weight gage of the type described by Keyes (9). Pressure could be read to 1 lb./sq.in. Temperatures were measured by means of iron-constantan thermocouples (No. 28 wire), a Leeds and Northrup Type *K-II* potentiometer and type *R* galvanometer. Sensitivity was such that measurements could be made to 0.2 microvolts. The thermocouples were calibrated against a mercury in glass thermometer with graduations to 0.1° C. certified by the National Bureau of Standards. Calibration was necessary only for determining the temperature level of the sample gas, and was not of importance in determining the thermal conductivity.

Theory

Under certain conditions and after a steady state has been reached the thermal conductivity of the sample gas bears a linear relationship to the ratio of the temperature differences across the inner and outer thermal resistances. These are the resistances that lie between thermocouples Z_1 and Z_2 and between Z_2 and Z_3 respectively. These conditions are listed below and will be discussed in turn.

1. In the region midway between the ends of the apparatus the radial heat flow through the outer resistance of the apparatus is equal to the heat flow through the inner resistance.
2. The thermal conductivity of the test gas alone changes with pressure, and the thickness of this layer remains constant.
3. The apparatus is sufficiently symmetrical so that the heat flows through the respective resistances in series and the effect of circumferential heat flow is negligible. In particular, the effective width of the sample gas layer is independent of the thermal conductivity of the gas.
4. The radiation error is negligible.
5. Convection in the gas layers is absent.

Under these conditions the outer resistance is constant and the inner resistance may be divided into two parts, one independent of the sample gas thermal conductivity and one inversely proportional to its thermal conductivity. For the outer resistance,

$$q_N = \frac{\Delta t_N}{C} \qquad (1)$$

and for the inner resistance

$$q_x = \frac{\Delta t_x}{\frac{\beta'}{k} + \gamma'} \qquad (2)$$

But $q_N = q_x$, and by dividing Equation (2) by Equation (1), and rearranging,

$$R' = \frac{\Delta t_x}{\Delta t_N} = \frac{\beta}{k} + \gamma \qquad (3)$$

where β and γ are new constants.

That the five conditions listed above were actually met in the design and operation of the method is indicated primarily by the linear calibration curves obtained. However, this is not conclusive evidence and each of the conditions will be discussed.

Condition 1 requires for the portion of the apparatus where measurements are made that only radial heat flow exist. This condition was very nearly met by adjusting the temperatures at the ends of the apparatus, employing secondary heating or cooling as required at each end, so that the temperature gradient along the length of the apparatus was very small. The length of the apparatus was also governed by the necessity for providing significant resistance in this direction. A slight correction was applied to account for the small temperature gradient measured along the length, in accordance with the fin equations; the correction amounting to an almost negligible amount. The middle temperature, t_1 (*See* Fig. 2) was not critically sensitive to the slight changes in the values of t_0.

Condition 2 implies that there is no change in resistance except that due to the change in thermal conductivity of the sample gas with pressure. A correction is required due to deviations from this condition. As the pressure of the sample gas increases the width of this layer increases slightly. This results in the measured value of thermal conductivity being low. Based upon the equations for strain in cylinders of infinite length the change of gap width with pressure was calculated. For internal pressure,

$$\Delta W = \frac{14.69 P r_a}{E}\left(\frac{r_a^2 + r_b^2}{r_b^2 - r_a^2} + u\right) \qquad (4)$$

and for external pressure

$$\Delta W = \frac{-14.69 P r_b}{E}\left(\frac{r_b^2 + r_a^2}{r_b^2 - r_a^2} - u\right) \qquad (5)$$

But

$$k = k_a\left(\frac{W}{0.008}\right) \qquad (6)$$

From Equations (4), (5), and (6) combined this correction was found to be

$$k = k_a(1 + 1.21 \times 10^{-4} P) \qquad (7)$$

Equation (7) was used to correct the measured conductivities k_a, a correction amounting to 2.4% at 200 atm.

Condition 3 will be met if circumferential heat flow either in the gas layers or in the steel does not distort the temperature distribution in the middle of the apparatus from a circle or change the magnitude of the temperature differences. The magnitude of this source of error was calculated for two assumed limiting cases. Consideration of these cases indicates that in general moderate eccentricity does not lead to appreciable errors. This is so because the gas layer is thin and has a high thermal resistance in the circumferential direction so that heat flow through the gas layer is almost entirely radial. This results in a greater heat flow through the thinner portions of the layer and a circumferential heat flow in the steel. However, the resistance to this flow in the steel is so low that the temperature is nearly uniform in the steel at any given radius. The result is essentially the same as though the gas layer were of uniform thickness and all heat flowed radially. The effect of eccentricity may, however, become appreciable at large eccentricities especially when the walls of the gas layer touch at any point.

Radiation through the gas layers permits heat flow which is independent of the thermal conductivity of the gas in the layer. When the simultaneous heat transfer by radiation and conduction is taken into account an equation considerably more complicated than Equation (3) results.

The heat transferred by radiation from metal wall to metal wall through the gas layer is given by

$$q_r = 0.173A\frac{\epsilon}{2-\epsilon}\left[\left(\frac{T_h}{100}\right)^4-\left(\frac{T_c}{100}\right)^4\right] \tag{8}$$

where q_r is the heat transferred by radiation, A is the area of heat interchange, ϵ is the emissivity of the walls, and T_h and T_c are the absolute temperatures of the hotter and colder wall surfaces respectively, in degrees R. The total heat transfer, q_t, across a gas layer is

$$q_t = q_k + q_r \tag{9}$$

where q_k is the heat transferred by conduction, and there is no convection. Considering conduction only, let the thermal resistance of the gas thickness of the outer layer be denoted by R_A, and the metal thickness thermal resistance of the outer layers by R_B. Then by the principle of equal heat flow through the various layers,

$$\frac{\Delta t_A}{R_A} + 0.173A_A\frac{\epsilon}{2-\epsilon}\left[\left(\frac{T_{hA}}{100}\right)^4-\left(\frac{T_{cA}}{100}\right)^4\right] = \frac{\Delta t_B}{R_B} \tag{10}$$

where the subscripts A and B refer to the gas and metal thicknesses respectively. For simplification, let

$$f(T)_A = 0.173A_A\frac{\epsilon}{2-\epsilon}\left[\left(\frac{T_{hA}}{100}\right)^4-\left(\frac{T_{cA}}{100}\right)^4\right] \tag{11}$$

For the inner layer of thermal resistances, an equation similar to 10 can be written,

$$\frac{\Delta t_c}{R_c} + f(T)_c = \frac{\Delta t_D}{R_D} \tag{12}$$

The subscript C refers to the inner gas layer, and the subscript D refers to the metal thickness of the inner layers. Equation (10) can be transformed to

$$\frac{\Delta t_A}{R_A} + \frac{\Delta t_B}{R_A} = \frac{\Delta t_B}{R_B} + \frac{\Delta t_B}{R_A} - f(T)_A \tag{13}$$

and Equation (12) can be treated similarly. But $\Delta t_A + \Delta t_B = \Delta t_N$ and $\Delta t_C + \Delta t_D = \Delta t_s$, where Δt_N and Δt_s are the temperature differences across outer and inner thermal resistances respectively. Combining Equation (13) and the similar equation for the inner thermal resistance results in the relation,

$$\frac{\Delta t_s}{\Delta t_N} = \frac{\Delta t_D\left[1+\frac{R_C}{R_D}-\frac{R_C f(T)_C}{\Delta t_D}\right]}{\Delta t_B\left[1+\frac{R_A}{R_B}-\frac{R_A f(T)_A}{\Delta t_B}\right]} \tag{14}$$

Applying again the principle of equal heat flow through each layer,

$$\frac{\Delta t_D}{\Delta t_B} = \frac{R_D}{R_B} \tag{15}$$

Combining Equations (14) and (15), and multiplying,

$$\frac{\Delta t_s}{\Delta t_N} = \frac{R_D + R_C - \frac{R_D R_C f(T)_C}{\Delta t_D}}{R_B + R_A - \frac{R_B R_A f(T)_A}{\Delta t_B}} \tag{16}$$

By cross-multiplying and rearranging terms,

$$\frac{\Delta t_s}{\Delta t_N} = \frac{R_D + R_C}{R_B + R_A} + \frac{\Delta t_s R_B R_A f(T)_A}{\Delta t_N (R_B + R_A)\Delta t_B} - \frac{R_D R_C f(T)_C}{(R_B + R_A)\Delta t_D} \tag{17}$$

but

$$\frac{R_D + R_C}{R_B + R_A} = \frac{\frac{\beta'}{k} + \gamma'}{C} = \frac{\beta}{k} + \gamma \tag{18}$$

The equation involving radiation is thus,

$$\frac{\Delta t_s}{\Delta t_N} = \frac{\beta}{k} + \gamma + \Phi \tag{19}$$

where

$$\Phi = \frac{\Delta t_s R_B R_A f(T)_A}{\Delta t_N C \Delta t_B} - \frac{R_D R_C f(T)_C}{C\Delta t_D} \tag{20}$$

The factor Φ can be arbitrarily written in the form

$$\Phi = \frac{\psi}{k} + \tau \tag{21}$$

where ψ is a constant of arbitrarily selected value, and τ is a function of k and the radial temperature distribution. Then Equation (19) can be written as

$$\frac{\Delta t_s}{\Delta t_N} = \frac{\beta + \psi}{k} + \gamma + \tau \tag{22}$$

The value of $\gamma + \tau$ can be computed from experimental measurements and the geometry of the apparatus if an emissivity is assigned to the highly polished steel walls. Arbitrarily assign a value of ψ such that $\tau = 0$ when carbon dioxide is the test gas used.

The calculated values of $\alpha + \tau$ in Table 1 show that for an emissivity of 0.24 this value changes by 1.8% for a ninefold change in thermal conductivity.

TABLE 1.—CALCULATED VALUE OF $\gamma + \tau$ AS A FUNCTION OF k

Gas	Thermal Conductivity B.t.u./(hr.)(ft.)(° F.) at 106° F.	Values of $\gamma+\tau$ $\epsilon = 0.24$	$\epsilon = 1.0$
Carbon dioxide	.0104	.3800	.380
Nitrogen	.0157	.3831	.403
Methane	.0210	.3845	.413
Helium	.0895	.3870	.431

The change is small primarily because the heat transferred through the extremely thin gas layers is so much greater by conduction than by radiation. The heat transfer by radiation through the test gas layer is about 1% of the total heat flow, and through the outer gas layer, 5%. The accuracy with which the conductivity of the calibrating gases is known is probably from 1 to 2%. The degree to which the value of $\gamma + r$ remains constant is a measure of the linearity of the calibration curves. The amount of curvature is of the order of the experimental error and of the accuracy with which the thermal conductivities of the gases used for calibration are known. It is possible that greater curvature was not observed due to a compensating effect.

The apparatus was calibrated at atmospheric pressure using nitrogen, methane, carbon dioxide, and helium. This consisted of evaluating the linear relationship in Equation (3) using the above gases of known thermal conductivity in the inner test gas layer and for a single temperature level and difference in temperature between thermocouples Z_1 and Z_3. Data for a typical case with methane in the outer gas layer are shown in Table 2. Values of k were obtained from the literature and the values of R' were measured.

Values of R' are shown plotted against $1/k$ on Figure 4 and a straight line results. To determine an unknown value of k, the temperature differences across the outer and inner thermal resistances are measured and the ratio R' determined. The value of k is then determined from Figure 4. When the gas in the outer layer, or the temperature at Z_1 or Z_2 is changed a new calibration line must be established. Calibration lines were obtained for three sets of thermocouples, namely, top, side, and bottom positions. The variation of these lines with location in the apparatus was small and was attributed to an uncertainty as to the radial position of the thermocouples and to slight variations in the thermocouples themselves. Corrections for these differences in thermocouples were not made separately but were included in the apparatus calibration. The values of thermal conductivity determined separately from the calibration curves for the top, side, and bottom sets of thermocouples agreed closely.

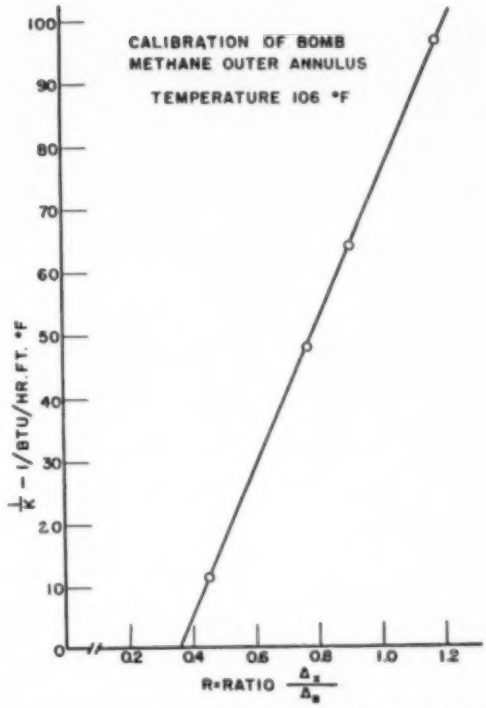

Fig. 4. Calibration curve for thermal conductivity bomb with methane in outer annulus, 106° F.

Experimental Procedure

The gases were obtained from commercial sources in cylinders under pressure. Further increase in pressure was accomplished by compressing the gas in a cylinder over mercury. The gases used and their purity were CO_2, 99.5%; N_2, 99.8%; CH_4, 99.0%; A, 99.6%; He, 98.0%; and H_2, 99.7%. These were used as received.

Gas was introduced into either annuli by evacuating the space, and then allowing the fresh gas to enter. This procedure was repeated five times leaving a residual old gas of less than 0.01%. The different gases were introduced into the outer annulus to change the resistance and obtain a convenient R' value. The nitrogen data were obtained with nitrogen in the outer gas layer; the hydrogen and helium data, with helium in the outer layer; and all other data, with methane in the outer gas layer. The choice of the outer layer gas was based upon obtaining a convenient value of outer thermal resistance. The function of this outer gas was primarily to serve as a thermal resistance, and an accurate knowledge of its thermal conductivity was unimportant.

Readings of the thermocouple voltages and pressure were taken 50 min. or more after a new gas pressure was established. It was found that 90% of the temperature change occurred in the first 15 min. after change of gas pressure.

The accuracy of the thermal conductivities measured depended on the accuracy of the calibration. R' values were measured for the four calibrating gases, nitrogen, methane, carbon dioxide, and helium, at atmospheric pressure.

With methane in the outer annulus, a temperature of 106° F., and the top set of thermocouples being used, four determinations of R' with nitrogen in the inner annulus were made. Values of R' of 0.908, 0.907, 0.907 and 0.906 were obtained. Similarly R' was measured nine times with methane in the inner layer, seven times with carbon dioxide, and six times with helium, with comparable precision. The tempera-

TABLE 2.—VALUES OF R' AS A FUNCTION OF THERMAL CONDUCTIVITY

Conditions:
Methane in outer gas layer.
Temperature of test gas, 106° F.
Over-all temperature difference, $Z_1 - Z_3$, 16° F.

Gas in Inner Layer	k Thermal Conductivity B.t.u./(hr.)(ft.)(° F.)	$1/k$	R'
CO_2	0.0104	96.3	1.180
N_2	0.0157	63.6	0.907
CH_4	0.0210	47.6	0.774
He	0.0895	11.17	0.452

Value of $\beta + \psi$, 0.00857. value of $\gamma + r$, 0.380.

TABLE 3

THERMAL CONDUCTIVITY OF NITROGEN AT 106° F.

Pressure Atmospheres	Thermal Conductivity Btu/hr. ft.° F.	Btu/hr. ft.° F. Keyes and Sandell
1.0	0.0157	0.0157
47.6	0.0166	0.0171
56.5	0.0171	0.0172
73.9	0.0176	0.0177
82.7	0.0179	0.0180
96.3	0.0184	0.0184
121.7	0.0191	0.0193
136.0	0.0200	0.0198
144.7	0.0201	0.0201
167.6	0.0209	
170.3	0.0210	
196.1	0.0222	
205.7	0.0223	

TABLE 4

THERMAL CONDUCTIVITY OF METHANE AT 106° F.

Pressure Atmospheres	Thermal Conductivity Btu/hr. ft. ° F.
1.0	0.0210
19.6	0.0219
36.7	0.0227
45.0	0.0231
57.9	0.0239
72.1	0.0248
84.6	0.0260
101.9	0.0269
115.6	0.0283
133.0	0.0292
167.5	0.0329
203.4	0.0365

TABLE 5

THERMAL CONDUCTIVITY OF ARGON AT 106 °F.

Pressure atmospheres	Thermal Conductivity Btu/hr. ft. °F.
1.0	0.0103
6.6	0.0112
37.6	0.0117
63.7	0.0121
92.3	0.0132
119.1	0.0139
144.6	0.0143
171.7	0.0155
194.1	0.0164

TABLE 6

THERMAL CONDUCTIVITY OF HELIUM AT 109 °F.

Pressure atmospheres	Thermal Conductivity Btu/hr. ft. °F.
1.0	0.0899
49.9	0.0929
68.4	0.0939
91.5	0.0930
95.9	0.0935
138.6	0.0958
143.1	0.0960
197.9	0.0979
205.2	0.0967

TABLE 7

THERMAL CONDUCTIVITY OF HYDROGEN AT 109 °F.

Pressure atmospheres	Thermal Conductivity Btu/hr. ft. °F.
1.0	0.112
42.9	0.116
82.7	0.117
111.2	0.123
126.5	0.123
166.4	0.129
179.8	0.128
206.7	0.133

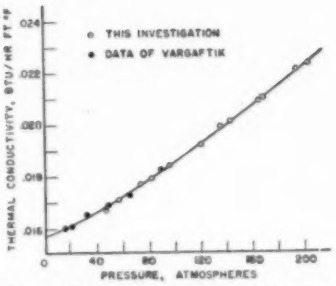

Fig. 5. Thermal conductivity of nitrogen 106° F.

ture of the inner gas layer was calculated and its thermal conductivity was determined from data in the literature as follows: (*3, 5-6, 18*) for nitrogen; (*5, 7, 12, 19*) for methane; (*3, 5, 7-8, 16, 19*) for carbon dioxide; and (*3, 5, 7-8, 19*) for helium. Values of $1/k$ were computed and large scale plots of $1/k$ against R' were made. A typical plot is shown in Figure 4.

Measurement of thermocouple voltages for each couple was repeated six times, and the results averaged. The value of the temperature difference ratio was evaluated as:

$$\frac{\Delta r}{\Delta N} = \frac{Z_a - Z_s}{Z_1 - Z_2} \qquad (23)$$

where here Z refers to the voltages produced by the thermocouples. The reading of thermocouple Z_s was corrected for end effect. The value of $1/k$ uncorrected for strain was obtained from Equation (3), using the constants in this equation obtained by calibration. Correction for strain was made using Equation (7), giving the desired thermal conductivity measurement. The average temperature of the sample gas was evaluated as the average of the temperatures corresponding to readings of thermocouples Z_s and Z_a, and for this purpose the separate thermocouple calibrations were taken into account. The temperature difference across the inner gas layer was determined by the equation

$$\Delta T_c = \Delta t_s \left(\frac{R' - K_a}{R'} \right) \qquad (24)$$

Experimental Results

Measurements on nitrogen were made at 106° F. and up to a pressure of 205.7 atm. This temperature was selected to allow comparison with Vargaftik's measurements which were made at 106° F. The measurements were taken with increasing pressure steps up to 205.7 atm., and then with decreasing pressure steps, to learn whether a hysteresis effect was present. Values obtained with increasing pressure steps agreed well with the values obtained with decreasing pressure steps. The precision of measurement was 1½%.

Values for the thermal conductivity of nitrogen are shown in Table 3 and are plotted on Figure 5 together with results obtained by Vargaftik. The

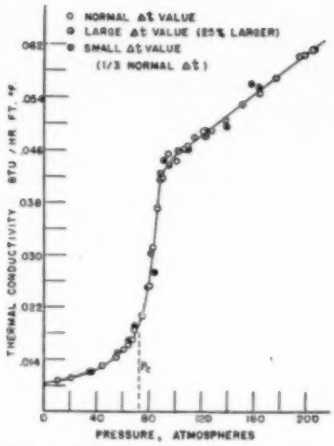

Fig. 6. Thermal conductivity of carbon dioxide 106° F.

agreement is excellent. Keyes and Sandell (*10*) have recently measured values of the thermal conductivity of nitrogen at various temperatures and pressures. A comparison is shown in Table 3 of the Keyes and Sandell values, obtained by their extrapolation of the data, with the values obtained in this investigation.

Results for other gases are shown in Tables 4-9. The precision of the measurements is believed to be 1½% at low values of thermal conductivity, but is less at higher values due to lower precision in measuring the resulting smaller temperature difference across the gas layer. A steady increase of thermal conductivity with increase in pressure occurred except that with carbon dioxide and ethylene the increase was much more rapid at pressures just above the critical pressure. The variation of the conductivity of carbon dioxide as a function of pressure is shown in Figure 6.

As a means of determining whether

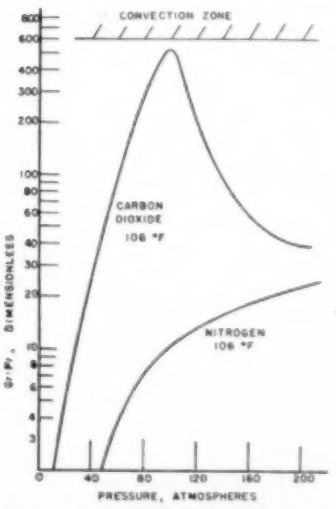

Fig. 7. Tendency of carbon dioxide and nitrogen to undergo convection as measured by Grashof and Prandtl number product.

TABLE 8

THERMAL CONDUCTIVITY OF ETHYLENE

Temperature ° F.	Pressure Atmospheres	Thermal Conductivity Btu/hr. ft. ° F.
106	1.0	0.0128
	19.3	0.0139
	41.4	0.0160
	59.4	0.0196
	82.5	0.0306
	103.0	0.0381
	123.1	0.0421
	145.0	0.0459
	164.1	0.0491
	176.9	0.0511
	203.0	0.0559
153	1.0	0.0148
	21.4	0.0157
	49.8	0.0181
	61.9	0.0194
	88.1	0.0251
	103.3	0.0284
	129.6	0.0341
	161.0	0.0403
	203.3	0.0463
	226	0.0496

TABLE 9

THERMAL CONDUCTIVITY OF CARBON DIOXIDE

Temperature °F.	Pressure Atmospheres	Thermal Conductivity Btu/hr. ft. ° F.
106	1.0	0.0104
	21.3	0.0112
	44.6	0.0129
	60.8	0.0155
	79.3	0.0248
	86.3	0.0371
	101.0	0.0444
	110.2	0.0467
	122.1	0.0490
	152.1	0.0529
	177.7	0.0571
	205.3	0.0614
134	1.0	0.0111
	28.1	0.0123
	56.2	0.0142
	65.8	0.0154
	79.4	0.0183
	103.0	0.0274
	120.0	0.0370
	150.9	0.0447
	190.5	0.0500
	201.5	0.0515
153	1.0	0.0116
	21.8	0.0125
	49.8	0.0142
	67.2	0.0155
	81.5	0.0178
	101.5	0.0224
	120.2	0.0283
	143.8	0.0360
	186.4	0.0448
	200.1	0.0462

convection was present a series of measurements was made at various temperature differences across the test gas layer. If convection was absent the resulting measured value of thermal conductivity would be independent of the temperature difference. Measurements were made at three over-all temperature differences (corresponding to $Z_1 - Z_3$) namely, 16° F., 20° F., and 5.33° F. Measurements taken with a 16° difference constituted the bulk of the data, and these are listed as the results obtained with normal Δt in Tables 3-9. The 20° F. and 5.33° F. measurements were made to check for convection and within the limits of experimental error it was found that the measured values of thermal conductivity were independent of temperature difference. These values are shown in Figure 6.

As a second means of testing for convection, values of the Grashof and Prandtl numbers were computed, taking into account the nonideality of the gases at high pressure. In general the value of Gr.Pr. increased rapidly with pressure. For the gases which were relatively close to the critical state the value of Gr.Pr. was found to reach a maximum at a pressure somewhat above the critical pressure. The sharpness of the maximum was more marked the closer the critical temperature was approached. In the case of carbon dioxide the gas approached closely to the conditions of incipient convection, and it was evident that an attempt to approach closer to the critical temperature would have resulted in convection. The variation of the Gr.Pr. product with pressure for carbon dioxide and nitrogen is shown on Figure 7. In no case was a value of Gr.Pr. found to be higher than 600.

A further test was made on that section of the data which was obtained under conditions of incipient convection. At 106° F. and 105 atm., a number of measurements were made on carbon dioxide at temperature differences ranging from one third to twice the normal temperature difference. The apparent thermal conductivity is shown as a function of this ΔT in Figure 8. The onset of convection is marked by the increase in apparent thermal conductivity. Below a critical Gr.Pr. number of 760 the measured value of thermal conductivity was found to be independent of temperature difference. Above 760, the value of the apparent thermal conductivity increased with increasing temperature difference. This critical value of 760 should not be considered precise because of the difficulty of evaluating the properties of the gas near the critical temperature and pressure. It does, however, indicate the applicability of the Kraussold relation at high pressures. These latter tests also indicated that convection could be identified when present and served to establish the limits of the apparatus in this respect.

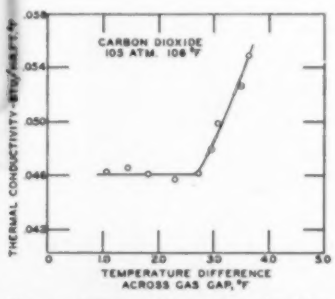

Fig. 8. Apparent thermal conductivity as measured increases abruptly when convection sets in.

Correlation of Results

The thermal conductivity ratio has been plotted against the reduced pressure for various reduced temperatures on Figure 9. The thermal conductivity ratio as predicted by the Comings and Nathan (*2*) correlation is shown by the curved lines. The arrow indicates the correlation curve with which a given group of data is to be compared.

The correlation fits the nitrogen results well with a maximum difference of 3½% at 200 atm. The correlation is low for argon and equally high for methane. In general, it predicts an average value when different gases are considered. At reduced pressures greater than 2, it tends to predict low values for carbon dioxide and high values for ethylene. In the region near the critical it predicts low values, by as much as 20%. This is attributed to the fact that the curves were based on scanty data in this region. The curves were dotted lines to show that reliance should not be placed on the correlation in this region. In summary the Comings and Nathan correlation fits the data with an average discrepancy of 4%. In the region of the critical, it gives values that are low by as much as 20%.

M. F. Nathan constructed and tested two preliminary designs of thermal conductivity cell utilizing dual annular layers of fluid with known and unknown thermal conductivity and proposed the addition or removal of heat at the ends of the cylinder to correct for heat flow in these regions. The investigation was carried out under a fellowship provided by the Pan American Refining Corp.

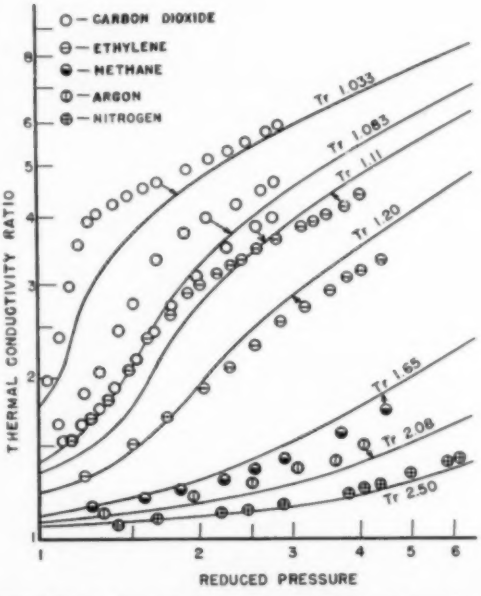

Fig. 9. Comparison of measured values of thermal conductivity with correlation by Comings and Nathan.

Notation

A = area across which heat is being transferred, sq.ft.

A_A = area of heat interchange across outer layer of gas, sq.ft.

C = a constant thermal resistance, (hr.)(° F.)/B.t.u.

E = modulus of elasticity of steel

$f(T)_A$ = function of radiation heat transfer across outer gas layer

$f(T)_C$ = function of radiation heat transfer across inner gas layer

Gr = Grashof number

k = thermal conductivity, B.t.u./(hr.)(ft.)(° F.)

k_a = apparent thermal conductivity including convection, B.t.u./(hr.)(ft.)(° F.)

k_1 = thermal conductivity of gas at 1 atm., B.t.u./(hr.)(ft.)(° F.)

P = pressure, atm.

Pr = Prandtl number

q_k = heat transfer through gas by conduction, B.t.u./hr.

q_N = heat transferred across outer layer of thermal resistances, B.t.u./hr.

q_r = heat transferred through gas by radiation, B.t.u./hr.

q_t = heat transferred by radiation and conduction, B.t.u./hr.

q_x = heat transferred across inner layer of thermal resistances, B.t.u./hr.

R = resistance to heat flow by conduction (hr.)(° F.)/B.t.u.

R_A = resistance to heat flow by conduction across outer gas layer, (hr.)(° F.)/B.t.u.

R_B = resistance to heat flow of metal walls of outer thermal resistance, (hr.)(° F.)/B.t.u.

R_C = resistance to heat flow by conduction of inner gas layer, (hr.)(° F.)/B.t.u.

R_D = resistance to heat flow of metal walls of inner thermal resistance, (hr.)(° F.)/B.t.u.

R_0 = ratio of inner to outer temperature difference when the gas in the inner layer has zero thermal resistance

R' = ratio of inner to outer layer temperature differences

r_a = radius of the inner wall of a cylinder, in.

r_b = radius of the outer wall of a cylinder, in.

T_h = temperature of hotter wall surface, ° R.

T_{hA} = temperature of hotter wall surface facing the outer gas layer, ° R.

T_{cA} = temperature of cooler wall surface facing the outer gas layer, ° R.

T_c = temperature of cooler wall surface, ° R.

t = temperature, ° F.

t_f = temperature of central steel tube when $t_0 = t_1$, ° F.

t_0 = temperature of one end of apparatus, central tube, ° F.

t_1 = temperature of central tube at the middle section, ° F.

u = Poisson's ratio

W = width of the inner gas layer, ft.

Z_1 = thermocouple No. 1 (*see* Fig. 2)

Z_2 = thermocouple No. 2

Z_3 = thermocouple No. 3

GREEK:

β = constant in calibration equation, $= \beta'/C$

β' = constant in calibration equation

γ = constant in calibration equation, $= \gamma'/C$

γ' = constant representing thermal resistance of inner layer other than that of the test gas

ΔN = e.m.f. difference across outer thermal resistance, *mv.*

Δx = e.m.f. difference across inner thermal resistance, *mv.*

ΔT_A = temperature difference across outer gas layer, ° F.

ΔT_B = temperature difference across metal walls and discontinuity of outer thermal resistance, ° F.

ΔT_C = temperature difference across inner gas layer, ° F.

ΔT_D = temperature difference across metal walls and discontinuity of inner thermal resistance, ° F.

Δt_N = temperature difference across outer thermal resistance, ° F.

Δt_x = temperature difference across inner thermal resistance, ° F.

ΔW = change in width of inner gas layer, ft.

ϵ = emissivity factor

Φ = over-all function of radiation heat transfer

τ = function of radiation

ϕ = a constant arbitrarily assigned, in conjunction with τ

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Discussion

Donald K. Katz (University of Michigan, Ann Arbor, Mich.) Has a correlation of thermal conductivity been tried which employs the volumes of the various fluids?

J. M. Lenoir: If the thermal conductivity values are plotted against specific volume instead of pressure a smooth curve results which does not show a pronounced hump in the region of the critical pressure. The data were plotted against pressure both to indicate the rapid change of thermal conductivity with pressure around the critical region and also for simplicity in using the graphs.

Anonymous: Has any work been done in connection with thermal conductivity of gas mixtures?

J. M. Lenoir: No.

(*Presented at Forty-second Annual Meeting, Pittsburgh, Pa.*)

DETERMINATION OF LIQUID-FILM ABSORPTION COEFFICIENTS

A New Type of Column and Its Application to Problems of Absorption in Presence of Chemical Reaction

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A new type of laboratory absorption column is described which is suitable for the determination of liquid-film matter transfer coefficients when, as is frequently the case, reliable data on rates of diffusion are not available. This gives results for physical solution similar to those obtained in packed towers. If, therefore, the relative performance of the laboratory column and various packings is established first for a known system (such as carbon dioxide-water) it is possible to predict the liquid-film coefficient for other systems with these packings by means of laboratory experiments. This procedure has the advantage of avoiding use of large quantities of gas and liquid necessary for experiments on a semitechnical scale. It is particularly convenient when it is required to determine absorption coefficients for systems which involve chemical reaction in the liquid.

An account is given of experiments on the absorption of chlorine from mixtures with air into an aqueous liquor containing ferrous and ferric chlorides (initial composition 23.5 lb. $FeCl_2$/cu.ft.; final composition 28.7 lb. $FeCl_3$/cu.ft. using this type of column. A correlation is presented covering the effects of liquid rate, concentration of unconverted ferrous chloride, and partial pressure of chlorine in the gas. It is shown that the results are consistent with the assumptions that a rapid reaction takes place in a narrow zone within the liquid film, and the rate of absorption is controlled by the rates of diffusion of the reactants.

WHEN a packed tower has to be designed for a new process involving absorption or stripping it is frequently impossible to calculate the matter transfer coefficient theoretically, unless it is known that the rate of transfer is controlled by the gas film. If the liquid-film resistance is important, prediction of the coefficient for physical solution may be prevented by lack of knowledge of the rate of diffusion in solution: and if a chemical reaction occurs in solution the process is more complicated, and data for use in calculations are rarely available. It is necessary therefore in many cases to determine absorption coefficients experimentally.

Now if the experiments are performed on a semitechnical scale with the actual packing it is proposed to use in the final design, the quantities of gas and liquid required will generally be large and in some circumstances may be prohibitive. There is therefore a need for laboratory scale equipment which will give results that can be simply related to those obtained with full-scale packings. Suitable apparatus has been developed in recent years in the engineering research departments of Imperial Chemical Industries, Ltd., at Billingham and Widnes; a description of this, together with its application to a problem of absorption in the presence of chemical reaction, forms the subject of this paper.

Part 1. Development of Laboratory Absorption Column

Historical. The simplest laboratory apparatus for the study of matter transfer between a gas and a falling film of liquid is the wetted-wall column. This has been successfully used in the study of systems for which the rate of transfer is controlled by the gas film, such as evaporation of liquids into a stream of air (*4*) and distillation (*7*); results obtained can be correlated by analogy with the related process of heat transfer in straight pipes. The conditions existing in the falling film of liquid are more complicated, however, since the range of liquid rates of practical interest corresponds to Reynolds numbers ($4\Gamma/\mu$) between 20 and 100; in this region flow is theoretically streamline but is complicated by ripple formation at the liquid surface (*5*). Attempts to correlate the results of determinations of liquid-film coefficients using wetted-wall columns were unsuccessful; moreover the coefficients were not independent of the length of the column.

It was decided therefore to develop a column in which the film of liquid was interrupted at short intervals during its descent, thus simulating the conditions of flow over a packing.

The first experiments on these lines were done with notched wetted-wall columns constructed from short thick-walled cylin-

NOTE: Complete Tables 1, 2, 3 and 7 are on file (Document 3127) with American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Obtainable by remitting $1.00 for a microfilm and $2.85 for photocopies.

drical sections of tube in series; the lower end of each section was bevelled so as to form a notch about ¼ in. deep. Columns were constructed with notches 1 in. and 4 in. apart respectively, and it was found that the effect of the column length on the liquid-film coefficient was satisfactorily eliminated. This type of column was, however, open to several objections of which the most important were:

a. The limiting gas velocity was substantially lower than for a normal wetted-wall column, being less than 5 ft./sec. at high liquid rates for a column ½-in. diameter with 1-in. pitch notches.
b. The gas-film coefficient was increased by the roughness effect produced by variation of the thickness of the liquid film in the neighborhood of the notches. It was considered that with columns of small diameter this effect would vary with the physical properties of the liquid, so that prediction of the gas-film coefficient would be inaccurate.

The modified wetted-wall column was therefore abandoned in favor of a new type of apparatus in which the liquid was caused to flow over a series of discs arranged in a single vertical row, with alternate discs at right angles. This arrangement can be regarded as roughly equivalent to a grid packing with a single element in each course. It has been found to give results for carbon dioxide absorption in water which are independent of the length of the column, and which can be related simply to the performance of packed towers on the same system. It has therefore been adopted in Imperial Chemical Industries (I.C.I.) as a standard laboratory column for determination of liquid-film coefficients, as described below.

General Description of the Disc Column. The standard form of the disc column consists of a suitable number (20-50) of discs of metal or unglazed ceramic material of low porosity, enclosed in a glass tube of about 2.5-cm. bore. The standard dimensions for the discs are 1.45- to 1.5-cm. diameter and 0.44- to 0.46-cm. thickness. The discs are threaded edgewise on a vertical wire (16 *s.w.g.* or about 1.6-mm. diameter), and successive discs are maintained at right angles by means of a suitable cement.

The general arrangement is shown in Figure 1. The liquid is fed, after metering, through a tube which terminates in a jet through which the supporting wire passes, and liquid is removed by a central tube and small funnel under the lowest disc, as shown. The distance between the element and the gas inlet should be as large as can be arranged, in order to provide a calming section for gas flow. It is important to ensure that:

1. The liquid feed jet is located 4 to 5 cm. above the uppermost disc. Greater distances tend to cause excessive splash, and if the distance is too small abnormal behavior has been observed in short columns—attributed to imperfect wetting of the first few discs.

2. The feed tube is wide enough to prevent the formation of air locks—about 8-mm. bore is satisfactory with water, with a jet of approximately 3-mm. diameter. The length of the tube and the jet size, however, may have to be adjusted to suit the liquid rate to be used and the pressure within the column.

3. The tube used for removal of liquid is 10 mm. or over in bore, so as to avoid entrainment of gas. When running, the liquid level in this tube should be near the upper end so that additional absorption surface is not provided by a film on the tube wall.

4. The gas inlet connections are of wide bore. This is important because long calming sections are rarely practicable.

Provision is made at the base of the column for the removal of any liquid which collects there as a result of splash from the discs. This is normally small for water unless liquid rates (referred to the mean perimeter of the wetted surface) exceeding 400 lb./(hr.)(ft.) are used. A modification in which the discs are located by means of shallow slots in their lower edges can be used to reduce splash at these rates, but it is then difficult to obtain complete wetting below 200 lb./(hr.)(ft.). For normal work the plain discs secured with a cement are preferred.

The choice of materials for the discs and wire depends on the substances with which the column is to be used. For corrosive conditions ceramic discs supported by a Fiberglas thread have been satisfactorily employed. Glazed or polished surfaces are to be avoided as they are difficult to wet; for the same reason it is essential to free the apparatus from traces of grease before use.

Characteristics of Disc Column for Absorption by Physical Solution. If liquid-film coefficients for new systems in packed towers are to be predicted by means of experiments with the disc column, it is necessary first to establish its characteristics for a system, such as carbon dioxide-water, for which the necessary physical properties are known.

In the development of the new column, experiments were made at Billingham and Widnes on the absorption of pure carbon dioxide in water, using discs which differed slightly from those subsequently adopted as standard. These showed that different installations could vary in performance, at the same wetting rate, by about ±10%; but the differences could not be correlated with variations in the dimensions of the discs. Smaller variations may be expected between different columns all constructed from the standard discs, but it is still considered desirable to determine the characteristics of individual columns before using them to investigate new absorption problems.

When the column is used with dilute gas mixtures the liquid-film coefficient has to be calculated from the observed over-all coefficient; this requires a knowledge of the gas-film coefficient for the conditions of the experiment. The performance of the column must therefore be known for at least one system for which absorption is substantially controlled by the gas film. This will always have to be determined for individual columns, since even with discs of standard dimensions conditions in the gas phase will be affected by the diameter of the outer tube.

The behavior to be expected will now be illustrated by means of experimental results obtained with the column used later

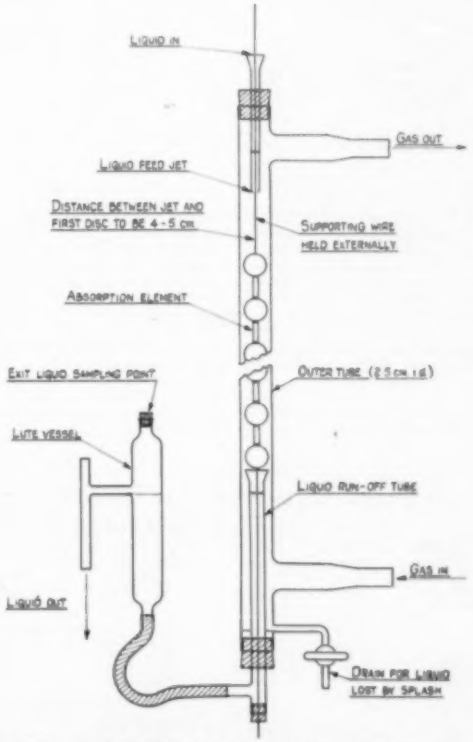

Fig. 1. Arrangement of disc absorption column.

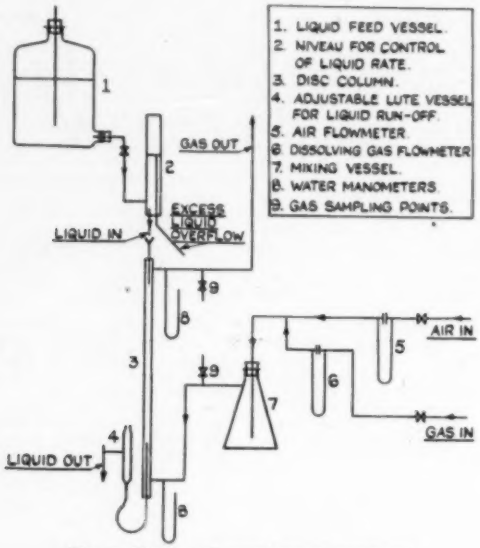

Fig. 2. Outline of experimental apparatus. (For details of disc column see Fig. 1.)

TABLE A

Number of discs	40
Disc diameter	0.57 in. (1.45 cm.)
Disc thickness	0.155 in. (0.394 cm.)
Tube diameter	0.988 in. (2.51 cm.)
Mean perimeter for liquid flow	0.115 ft.
Equivalent diameter for gas flow	0.051 ft.
Free space (dry)	90%
Absorption surface *	0.22 sq.ft.

* Uncorrected for film thickness or for loss of surface at points of contact, but used throughout as an approximation to the true liquid surface.

for the work on absorption with chemical reaction. The sections comprise a general description of the apparatus; an account of experiments on absorption of pure carbon dioxide in water, to establish the characteristics of the column with respect to the liquid film; and details of experiments on absorption of ammonia gas in water, from dilute mixtures with air; which served to determine the characteristics of the column with respect to the gas film.

A. *Description of Apparatus.* An outline of the apparatus used is shown in Figure 2. Liquid was supplied from a constant head reservoir (1) to a flowmeter of the "niveau" type (2) with a variable working level and interchangeable jets, operated so that a small excess of liquid overflowed continuously. In this way the liquid rate was maintained at a steady value; the actual rate was, however, measured at the run-off from the column in each experiment. Liquid then entered the disc column (3) and was withdrawn at the base through an adjustable lute vessel (4). Liquid temperatures were measured in this vessel and in the meter (2).

Air from compressed air supply and gas from cylinders were metered by capillary flowmeters (5) and (6) and the combined stream was mixed by passing through the empty vessel (7) before entering the column. In the experiments with carbon dioxide alone the gas passed directly from flowmeter (6) to the column.

The column used had an element supported by a Fiberglas thread maintained under tension. The principal dimensions are shown in Table *A*.

B. *Liquid-Film Coefficients. System Carbon Dioxide-Water.* Determinations were made over the range of liquid rates $\Gamma = 60 - 400$ lb./(hr.)(ft.) with the column just described and also with a shorter column of 24 discs (absorption surface 0.132 sq.ft.).

1. *Experimental Procedure.* Distilled water was used. This was shown to be free from carbon dioxide within the accuracy of the determinations.

Carbon dioxide from cylinders was passed through the tower at about 10 cu.ft./hr., a sufficient excess to ensure that air displaced from solution was rapidly removed from the column. The purity of the gas was tested from time to time, and allowance was made for traces of inerts and for variation in the atmospheric pressure when calculating the equilibrium concentration in the water. The purity of the carbon dioxide was generally 99% or better.

The liquid-film coefficient, equal in this case to the over-all coefficient, was calculated from the mass of carbon dioxide absorbed (lb./hr.) and the log mean concentration difference (lb./cu.ft.) based on the differences between the equilibrium and actual concentrations of dissolved gas at the ends of the column. Liquid temperatures varied over the range 16-22° C., and the coefficients were corrected to a constant temperature of 20° C., by means of the relation $k_L \propto e^{0.03t}$ obtained by Sherwood and Holloway (*11*).

2. *Results.* Results are given in Table 1 and shown graphically in Figure 3 in the form of a plot of liquid-film coefficient at 20° C., against the wetting rate Γ (equal to the water flow rate in pounds per hour divided by the mean perimeter for liquid flow in feet). It will be seen that there is good agreement between the results for the two lengths of column, and that they are well correlated by the equation:

$$k_L = 0.048\Gamma^{0.7} \text{ lb./(hr.)(sq.ft.)(lb./cu.ft.) at 20° C.} \quad (1)$$

This is consistent with the dimensional equation obtained by Sherwood and Hol-

TABLE 1.—CHARACTERISTICS OF THE DISC COLUMN: LIQUID-FILM COEFFICIENTS FOR THE ABSORPTION OF CARBON DIOXIDE IN WATER.

Run No.	Water Rate lb./hr.ft.	Water Temperature In °C.	Water Temperature Out °C.	Carbon Dioxide in Liquid Leaving, lb./cu.ft.	Carbon Dioxide Absorbed lb./hr.	Log Mean Driving Force lb./cu.ft.	Absorption Coefficient lb./hr.ft.² lb./ft.³ Observed	Absorption Coefficient lb./hr.ft.² lb./ft.³ Corrected to 20° C.
				40-Disc Column				
6	162	20.2	19.9	7.55×10^{-2}	2.26×10^{-2}	5.95×10^{-2}	1.72	1.74
13	306	21.0	21.0	6.61×10^{-2}	3.66×10^{-2}	6.15×10^{-2}	2.70	2.95
19	71	17.0	16.4	8.86×10^{-2}	1.17×10^{-2}	6.2×10^{-2}	0.86	0.93
				24-Disc Column				
28	68	17.4	17.2	7.02×10^{-2}	0.87×10^{-2}	8.0×10^{-2}	0.90	0.96
35	363	15.8	15.8	4.99×10^{-2}	3.33×10^{-2}	9.3×10^{-2}	2.73	3.00
38	142	18.3	18.2	5.86×10^{-2}	1.52×10^{-2}	7.8×10^{-2}	1.48	1.54

loway (*11*) from experiments with packed towers, which may be written in terms of coefficients on a surface area basis and the wetting rate Γ as:

$$\frac{k_L}{D} = a\left(\frac{4\Gamma}{\mu}\right)^n \left(\frac{\mu}{\rho D}\right)^{0.5} \quad \ldots \quad \text{ft.}^{-1} \tag{2}$$

where the value of (n) was found to vary between 0.54 and 0.78 for different packings, and a is a dimensional constant characteristic of the packing.

Characteristics of the disc column with respect to the liquid film are therefore similar to those of packed towers. It thus becomes possible to predict the coefficient for a packed tower by means of laboratory scale experiments, provided that the relation between the disc column and the packing to be used has been determined with a known system such as carbon dioxide-water.

It will be seen in Part 2 of this paper that in experiments with more viscous liquid the coefficient appears to depend on a lower power of Γ when the Reynolds number $4\Gamma/\mu$ is less than about 60. (This effect is not observed with water because the value of Γ corresponding to $Re = 60$ is only about 36 lb./(hr.)(ft.) at 20° C. which is outside the practicable range—being too low for complete wetting of the discs.) The practical consequence of this is that where determinations are required with liquids of viscosity greater than about 2 cps. it will be advisable to avoid working at liquid rates for which $4\Gamma/\mu$ is much below 60. If this is not done there may be a risk of overestimating the coefficient to be expected in a packed tower.

Assuming that a general equation of the type of Equation (2) can be applied to calculate the liquid-film coefficient for other conditions (in the absence of chemical reaction), then the constant a for the disc column can be evaluated from the above results. The resulting equation is:

$$\frac{k_L}{D} = 21.0\left(\frac{4\Gamma}{\mu}\right)^{0.7} \left(\frac{\mu}{\rho D}\right)^{0.5} \quad \ldots \quad \text{ft.}^{-1} \tag{3}$$

This equation was used to correct for the liquid-film resistance in the experiments on absorption of ammonia described in the following section.

C. Gas-Film Coefficients: System Ammonia-Air-Water. In order to establish the characteristics of the column with respect to the gas film, over-all coefficients were determined for absorption of ammonia in water from dilute mixtures with air (containing 3-5% NH_3 by volume). From the results the gas-film coefficients were derived, using liquid-film coefficients calculated from Equation (3) above.

1. *Experimental Procedure.* The apparatus outlined in Figure 2 was used, with the 40-disc column. The gas entering and leaving, and the liquid leaving the column were analyzed for ammonia. From these analyses a material balance was calculated for each run, and the result was rejected if the error exceeded 6%. In most of the experiments, balances within 2 to 3% were obtained. For calculating the over-all coefficient, however, the quantity of ammonia absorbed was derived from the liquid analysis, since this was considered to be more accurate than the difference in the gas tests.

The over-all coefficients (K_G) were obtained from the rate of absorption of ammonia and the log mean driving force in

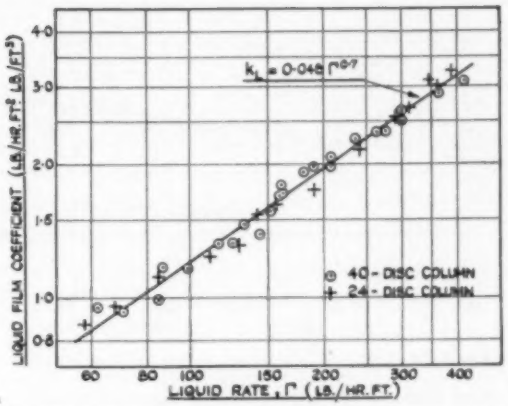

Fig. 3. Characteristics of disc column: liquid-film coefficients for absorption of carbon dioxide in water.

Values corrected to liquid temperature of 20° C.

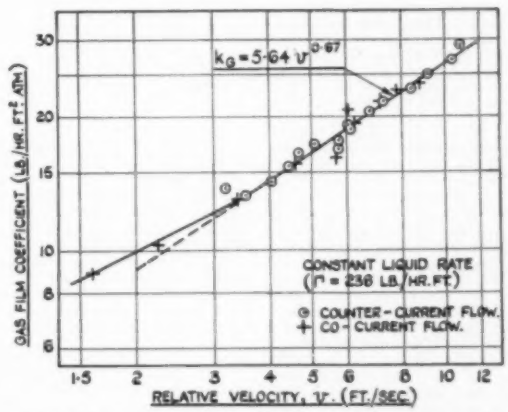

Fig. 4. Characteristics of disc column: effect of gas velocity on gas-film coefficient for absorption of ammonia in water.

TABLE 2.—CHARACTERISTICS OF THE DISC COLUMN: GAS-FILM COEFFICIENTS FOR ABSORPTION OF AMMONIA IN WATER, WITH VARIABLE GAS VELOCITY

Run No.	Gas * Velocity, ft./sec.	Relative Velocity, ft./sec.	Exit Liquid Composition lb. NH_3/cu.ft.	Log Mean Driving Force atm.	Overall Coefficient lb./hr.ft.²atm.	Gas Film Coefficient lb./hr.ft.²atm.	Material Balance %
				Counter-current Flow			
14	9.45	10.45	0.337	0.0273	23.9	27.0	97
17	3.45	4.45	0.262	0.0360	14.4	15.5	100
				Co-Current Flow			
19	8.8	7.8	0.288	0.0283	20.1	22.9	99
24	4.4	3.4	0.219	0.0355	12.2	13.0	103

Constant liquid rate $\Gamma = 236$ lb./hr.ft.

* The free space with liquid flowing was taken to be 86.5% at this liquid rate.

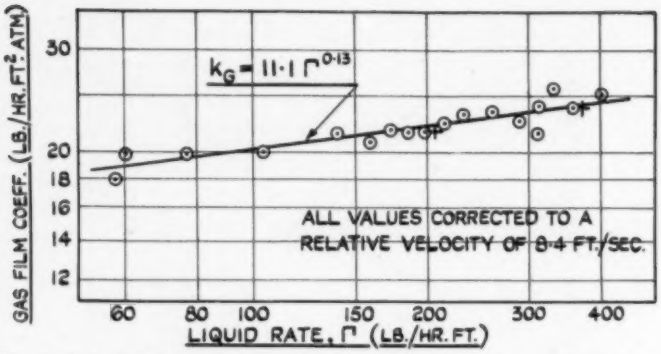

Fig. 5. Characteristics of disc column: effect of liquid rate on gas-film coefficient for absorption on ammonia in water.

(Runs shown as crosses were made at higher gas velocities to provide a check on correlation.)

terms of partial pressure. Liquid-film coefficients were then calculated for a liquid temperature of 20° C. by means of Equation (*3*) (taking the diffusion coefficient for ammonia in water to be 7.9×10^{-6} (sq.ft./hr.) and corrected for the mean liquid temperature by means of the temperature relationship of (*11*) as used in the work on carbon dioxide. Then, using the appropriate value of the Henry's law constant *H*, the gas-film coefficient was derived from the relation:

$$1/k_G = 1/K_G - 1/Hk_L$$

2. Results. Two series of experiments were carried out, in which the effect of gas velocity and liquid rate were examined. In the first series runs were made with both countercurrent and cocurrent flow, in order to establish whether it was necessary to allow for the velocity of the liquid surface.

Results of the experiments with variable gas velocity are given in Table 2. It was found that the results for countercurrent and cocurrent flow could only be correlated by making an allowance for liquid surface velocity; an effective value equal to ⅔ of the theoretical for streamline flow on a vertical surface (the latter is approximately 1.5 ft./sec. at the liquid rate used) enabled all the results to be correlated by a single line as shown in Figure 4 over the range of relative velocities from 3.6 to 10.8 ft./sec.

Data on the effect of liquid rate are given in Table 3 and shown in Figure 5. The relative velocity varied slightly during this series, and all results were corrected to a standard relative velocity of 8.4 ft./sec. by means of Figure 4. It will be seen that the gas-film coefficient at a given relative velocity increases with liquid flow rate, approximately as $\Gamma^{0.13}$. It could be seen plainly that the surface was fully wetted, at least for values of Γ above 95 lb./hr.ft.; and although the increase in film thickness with liquid rate gives a small increase in interfacial area with this arrangement, this is not sufficient to explain the observed rise in the coefficient. Presumably there must be an increase also in gas turbulence resulting from greater disturbance produced by liquid flowing over the junctions between successive discs as the liquid rate is raised. Similar effects have been observed with packed towers, where they have usually been attributed to changes in the wetted surface; these results suggest that this is not the only factor involved.

3. Application of Results to Other Gas Mixtures. It is seen from Figure 4 that the gas-film coefficient depends on the 0.67 power of the relative velocity for values of v above 3.6 ft./sec., corresponding to a Reynolds number for gas flow ($vd\rho/\mu$) of about 1100. This is consistent with a general correlation of the type applicable to wetted-wall columns (*4, 7*), viz.:

$$\frac{k_G P}{v\rho_d} = \beta \left(\frac{vd\rho}{\mu}\right)^{-n} \left(\frac{\mu}{\rho D}\right)^{-m} \frac{P}{p_{BM}} \qquad (4)$$

The value of n for the disc column used in this work was 0.33.

The constant β in Equation (4) may be deduced from the experimental results for ammonia absorption if a value is assumed for the index m which characterizes the effect of the group $\mu/\rho D$. The value $m = 0.56$ was selected, based on the data of Gilliland and Sherwood (*4*).

For the conditions of the experiments, 3-5% ammonia gas in air at approximately 20° C., and 1 atm. abs. pressure.

P = total pressure of gas	= 1 atm.
ρ_d = density of diffusing gas	= 0.044 lb./cu.ft.
D = absolute diffusion coefficient for ammonia in air	= 0.787 sq.ft./hr.
$\mu/\rho D$ = (dimensionless)	= 0.74
p_{BM} = mean partial pressure of inert gas in the film	= 0.98 atm. (approx.)
ρ = density of air at 20° C. and 1 atm.	= 0.075 lb./cu.ft.
μ = viscosity of air at 20° C. and 1 atm.	= 4.35×10^{-6} lb./(ft.)(hr.)

Under the conditions common to Figures 4 and 5 ($v = 8.4$ ft./sec. $= 3.02 \times 10^4$ ft./hr., and $\Gamma = 236$ lb./(hr.)(ft.) the mean value of the coefficient k_G is 23.0 lb./(hr.)(sq.ft.)(atm.).

Inserting these values in Equation (4) the value of the constant is found to be 0.19. The coefficient, however, varies with liquid rate according to the relation $k_G \propto \Gamma^{0.13}$.

Gas-film coefficients for the disc column used can therefore be calculated by means of the equation:

$$\frac{k_G P}{v\rho_d} = \beta \left(\frac{vd\rho}{\mu}\right)^{-0.33} \left(\frac{\mu}{\rho D}\right)^{0.56} \frac{P}{p_{BM}} \qquad (5)$$

where β is a function of the liquid rate. In consistent (ft.-lb.)(hr.) units:

$$\beta = 0.093\Gamma^{0.13}$$

Although it would be preferable to replace this function of Γ by an appropriate dimensionless group in Equation (5), and so avoid the use of a factor which varies with the units employed, the information at present available is not sufficient to enable this to be done.

Part 2. Application of Disc Column to Study of Chlorine Absorption in Solution of Ferrous and Ferric Chlorides

Processes in which gas absorption is accompanied by chemical reaction with a constituent of the liquid are frequently employed. The mechanism of absorption is one of physical solution followed by a reaction which may take place in a number of ways, as follows:

1. At the liquid surface: rate of absorption is then controlled by the gas film, and the coefficients can be readily calculated.
2. In a narrow zone within the liquid film: this mechanism applies when the reaction can take place rapidly compared with the rates of diffusion of reactants and products. Rate of absorption is then controlled by diffusion in the liquid.
3. During the diffusion of the dissolved gas through the liquid film: rate of absorption is then a function of both reaction velocity and rates of diffusion.

TABLE 3.—CHARACTERISTICS OF THE DISC COLUMN: GAS FILM COEFFICIENTS FOR ABSORPTION OF AMMONIA IN WATER, WITH VARIABLE LIQUID RATE

Run No.	Liquid Rate, lb./hr.ft.	Relative Velocity, ft./sec.	Exit Liquid Composition lb.NH₃/cu.ft.	Log Mean Driving Force atm.	Overall Coefficient lb./hr.ft.²atm.	Gas Film Coefficient lb./hr.ft.²atm. Observed	Corrected to $V = 8.4$ ft. Spec.	Material Balance %
3	104	7.8	0.516	0.0273	16.3	19.1	20.0	103.2
17	360	8.6	0.183	0.0247	22.1	24.1	23.9	98.3
21	206	9.6	0.286	0.023	21.3	24.0	21.8	102

Relative velocity calculated assuming the velocity of the liquid surface to be ⅔ of the theoretical value for streamline flow on a vertical surface in all cases.

4. In the main body of liquid: this occurs with slow reactions. With moderately slow reactions the concentration of free dissolved gas then takes up a value such that its rate of removal by reaction is balanced by the rate of diffusion through the liquid film. If reaction is very slow the liquid always may be practically saturated relative to the gas phase, and absorption is entirely controlled by the reaction velocity.

Quantitative information for use in design of absorption equipment for these processes is still limited. Much of the early work was carried out on batch absorption through the surface of stirred liquid, and the results are not applicable to the design of other equipment such as packed towers. Data for absorption of sulfur dioxide in caustic soda solution has been obtained by Johnstone and Singh (*8*) but this process is largely controlled by the gas film. Extensive work has been reported on the absorption of carbon dioxide in alkaline solutions. Thus Payne and Dodge (*9*), Comstock and Dodge (*1*) and Furnas and Bellinger (*3*) have studied absorption of carbon dioxide in alkali carbonate-bicarbonate solutions; coefficients for the systems carbon dioxide-alkali hydroxide solutions have been determined by Tepe and Dodge (*12*) and by van Krevelen and Hoftijzer (*13*) who also report data for ammoniacal solutions. Finally, the absorption of carbon dioxide by diethanolamine solutions has been studied by Cryder and Maloney (*2*).

A correlation of all these data for carbon dioxide absorption has been proposed by van Krevelen and Hoftijzer (*14*), based on a modification of the treatment originally worked out by Hatta (*6*) for absorption in stirred liquid; the mechanism is considered to be that for a reaction of moderate speed so that both reaction velocity and rates of diffusion affect the rate of absorption.

These authors have also (*14*) proposed a general theory which, it is claimed, enables the rate of absorption to be calculated for any system for which the liquid-film coefficient for physical solutions and the reaction velocity constant are known. In many cases, however, these data are unlikely to be available.

It is probable that the choice of systems for investigation has been limited by the large quantities of gas and liquid required for experiments with packed towers and the attendant problems of disposing of corrosive effluents. These difficulties are greatly reduced by the use of the new disc column. It was therefore decided to try out the column on a different system from those previously investigated, and for this purpose the absorption of chlorine by solutions of ferrous and ferric chlorides was selected. This system was chosen because:

1. Process is relatively simple in that the reaction is irreversible and gives only one product.
2. Analytical methods involved present little difficulty.
3. Materials are readily available.
4. Some data previously had been obtained with a wetted-wall column, which served to indicate the type of behavior to be expected.

Apparatus and Experimental Procedure. The apparatus consisted essentially of the 40-disc column described in Part I of this paper; the general arrangement was shown in Figure 2. The air flowmeter was calibrated, and the gas rate through the column was calculated from the air rate and the chlorine content of the gas. The chlorine flowmeter served only to ensure the maintenance of a steady flow of the magnitude required to give the desired inlet gas composition.

The amount of chlorine absorbed was calculated from the liquid rate and the change in liquid composition. This involved a difference between two relatively large values for the ferrous chloride concentration, and is only considered to be accurate to ±10%. The change in gas composition was, however, generally too low for a determination based on gas analyses, and it was not possible to attempt material balances.

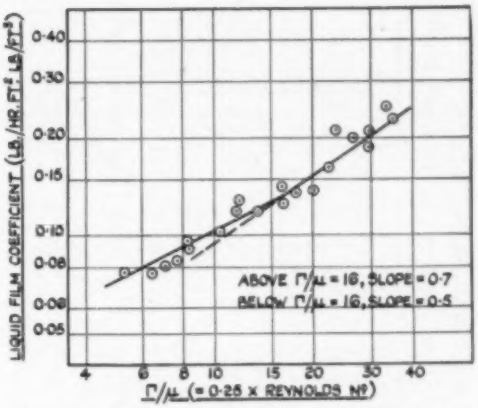

Fig. 6. Liquid-film coefficients for absorption in ferric chloride solution (28.7 lb./cu.ft.)

TABLE 4.—SOLUBILITY OF CHLORINE IN FERRIC CHLORIDE SOLUTION (28.7 lb./cu.ft.)

Partial Pressure (atm.)	Solubility (lb./cu.ft.)				
	15° C.†	17.5° C.	20° C.	22.5° C.	25° C.
0.4*	0.080	0.074	0.069	0.064	0.059
0.6	0.117	0.11	0.101	0.093	0.086
0.8	0.15	0.14	0.13	0.12	0.11
1.0	0.18	0.17	0.15	0.14	0.13

* Below 0.4 atm. the solubility is linearly proportional to the partial pressure.
† Extrapolated.

The over-all coefficient (K_G) was calculated from the rate of absorption and the mean chlorine partial pressure (p_A) in atmospheres; there was no chlorine partial pressure in equilibrium with the liquid.

The gas-film coefficient was calculated from Equation (5) (Part 1) and the value of the chlorine partial pressure (p_{Ai}) at the interface between the gas and liquid films was found by trial, such that $K_G p_A = k_G(p_A - p_{Ai})$. The proportion of the over-all resistance due to the gas film was, however, always small, and the resulting values of p_{Ai} were appreciably different from p_A only when using the most dilute gas mixtures.

Determinations of the solubility of chlorine at various partial pressures in the ferric chloride liquor produced by the reaction showed that Henry's law could be applied only up to a partial

TABLE 5.—VISCOSITY OF FERROUS/FERRIC CHLORIDE LIQUOR

Conc. of Residual Ferrous Chloride, c_R (lb./cu.ft.)	Viscosity at 20° C. (centipoises)
23.5	3.50
18.7	3.93
15.6	4.35
12.5	4.59
9.36	4.96
6.24	5.41
3.12	5.87
0.0 (i.e., 28.7 lb./cu.ft. of ferric chloride)	6.42

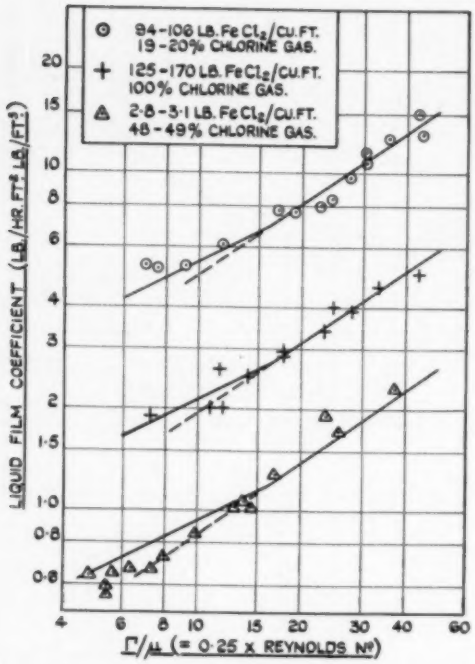

Fig. 7. Liquid-film coefficients for chlorine absorption in ferrous-ferric chloride solution: effect of liquid rate.

TABLE 6.—LIQUID-FILM COEFFICIENTS FOR PHYSICAL SOLUTION OF CHLORINE IN FERRIC CHLORIDE LIQUOR (28.7 lb./cu.ft.)

Run No.	Liquid Rate, lb./hr.ft.	Mean Temp. ° C.	Γ/μ	Liquid Film Coefficient lb./hr.ft.²lb./ft.³
9	290	18	17.8	0.136
11	218	19.5	13.7	0.119
15	85	18	5.25	0.077
19	557	19	35.0	0.228

pressure of about 0.4 atm. In order to correlate results obtained with 100% chlorine gas, therefore, the liquid-film coefficient was finally calculated using as driving force the equilibrium concentration at the interface (c_{Ai}) corresponding to the partial pressure p_{Ai}. The solubility data used are given in Table 4, obtained by smoothing graphically the experimental figures. It is not claimed that these are better than 5% accuracy, but they were considered adequate in view of the ±10% accuracy in determining the rate of absorption.

Range of Experiments. The solution used contained initially 23.5 lb. of ferrous chloride/cu.ft. with a trace of ferric chloride, and the corresponding fully chlorinated liquor contained 28.7 lb. of ferric chloride/cu.ft. (The density increases from 81.8 to 84.3 lb./cu.ft. and about 5% increase in volume occurs.)

Viscosity of the liquor increased with conversion to ferric chloride. Values shown in Table 5 were determined at 20° C.; it was assumed that over the range of temperatures involved (14-25° C.) the variation with temperature could be taken as similar to that of water.

The experiments fall into two main classes: (1) determination of absorption coefficients for physical solution of chlorine in the ferric chloride solution (28.7 lb./cu.ft.), and (2) determination of absorption coefficients for liquors containing unreacted ferrous chloride.

1. *Absorption Coefficients in Ferric Chloride Solution.* These experiments were done with 100% chlorine gas in a similar manner to those on the calibration of the column with the carbon dioxide/water system. Liquid rates from $\Gamma = 85$ to $\Gamma = 520$ lb./(hr.)(ft.) were covered, corresponding to a range of Reynolds numbers ($4\Gamma/\mu$) of about 20 to 130.

TABLE 7.—LIQUID-FILM COEFFICIENTS FOR CHLORINE ABSORPTION IN FERROUS/FERRIC CHLORIDE SOLUTION (INITIAL STRENGTH) 23.5 lb. $FeCl_2$/cu.ft.)

Run No.	Mean Temperature ° C.	Ratio of Liquid Rate to Viscosity Γ/μ	Mean Gas Composition % Cl_2	Conc. of Dissolved Chlorine at the Interface c_{Ai} lb./cu.ft.	Mean Conc. of Unreacted Ferrous Chloride c_B lb./cu.ft.	Liquid Film Coefficient lb./hr.ft.²lb./ft.³	Conc. Ratio c_B/c_{Ai}	Enhancement Factor: $\left(\frac{k_L^*}{\psi(\Gamma/\mu)^n}\right)$	Notes
6	17.5	19.2	19.2	0.0351	10.3	7.7	294	52	Series *A*. Effect of liquid rate, *see* Fig. 7.
9	21.5	44.8	18.9	0.0309	10.4	13.0	337	48.5	
22	19.1	27.9	100	0.158	15.2	3.9	96	20.5	Series *B*. Effect of liquid rate, *see* Fig. 7.
25	19.0	7.3	100	0.159	13.1	1.9	82.5	21.5	
45	20.5	17.6	100	0.151	10.4	2.35	69	17.5	Series *D*. Effect of gas composition, *see* Fig. 9.
47	19.8	17.3	10.6	0.0177	10.55	13.2	597	96	
52	20.6	17.5	23.8	0.0396	10.5	7.45	265	53.5	
62	20.8	17.8	23.5	0.0385	15.5	9.8	403	70	Series *E*. Effect of liquid composition (23-25% Cl_2), *see* Fig. 8.
67	19.7	18.3	24.8	0.0443	4.55	3.05	98.5	24	
69	24.2	21.8	9.75	0.0139	13.4	18.9	965	116	Series *F*. Effect of liquid composition (10% Cl_2), *see* Fig. 8.
75	18.5	14.6	10.2	0.0182	3.35	4.5	185	36	

* The constants ψ and n are taken from the correlation of Fig. 6 for physical solution:
For $\Gamma/\mu > 16$, $\psi = 1.87 \times 10^{-2}$, $n = 0.7$
For $\Gamma/\mu < 16$, $\psi = 3.35 \times 10^{-2}$, $n = 0.5$

2. Absorption Coefficients in Presence of Chemical Reaction. The effect of the following variables was investigated.

a. *Liquid Rate.* Reynolds numbers covered the range from 19 to 180.

b. *Liquid Composition.* Data were obtained at various stages in the conversion of the liquor from 23.5 lb. of ferrous chloride/cu.ft. to 28.7 lb. of ferric chloride/cu.ft. The range covered was from 0.94 to 23.4 lb. of unreacted ferrous chloride per cu.ft.

c. *Gas Composition.* The gas composition was varied from 3% to 100% chlorine by volume, at atmospheric pressure.

Individual series of experiments were made to determine separately the effect of these variables, and finally a large number of miscellaneous experiments were made to provide a check on the correlation proposed.

Results.

1. Absorption Coefficients in Ferric Chloride Solution. (28.7 lb./cu.ft.) Results of the experiments on physical solution in this ferric chloride solution are given in Table 6 and shown graphically in Figure 7, in the form of a plot of k_L against (Γ/μ). Above $\Gamma/\mu = 16$ approximately the results are consistent with those obtained in the calibration with the carbon dioxide-water system, i.e., $k_L \propto \Gamma^{0.7}$ but below this value the coefficient appears to depend on a lower power of the liquid rate. Thus for

$$\Gamma/\mu > 16,\ k_L = 1.87 \times 10^{-4}(\Gamma/\mu)^{0.7} \text{ ft./hr.}$$

and for

$$\Gamma/\mu < 16,\ k_L = 3.25 \times 10^{-3}(\Gamma/\mu)^{0.8} \text{ ft./hr.}$$

It will be seen later that a similar effect was found in the experiments where chemical reaction occurred.

2. Absorption Coefficients in Solutions of Ferrous and Ferric Chloride. Results of the experiments are given in Table 7. The effects of liquid rate, concentration of ferrous chloride in liquid (c_B), and concentration of dissolved chlorine at the interface (c_{Ai}) are shown in Figures 8-10.

Figure 8 shows the effect of liquid rate in three series of experiments at approximately constant gas and liquid composition. The lines shown were drawn on the assumption of a similar variation to that for physical solution (Fig. 6). It will be seen that this assumption is approximately correct, although there is some uncertainty concerning the behavior at low Reynolds numbers.

Figure 9 shows the effect of the ferrous chloride concentration (c_B), (i.e., degree of conversion of the liquor), from two series at approximately constant liquid rate; since the viscosity of the liquid increases with conversion to ferric chloride the results were corrected to a constant value of Γ/μ by means of Figure 6 before plotting. The coefficients are seen to depend on the 0.83 power of the ferrous chloride concentration.

Figure 10 shows the effect of gas composition, assuming that the liquid at the interface consists of a solution of chlorine in ferric chloride liquor, saturated with respect to the gas phase (with a small correction for the effect of the gas film, appreciable only for the most dilute gas mixtures). Direct correlation with the chlorine partial pressure was not possible on account of the deviations from Henry's law above 0.4 atm. These results show that the coefficients depend approximately on the inverse 0.81 power of the concentration of dissolved gas at the interface, c_{Ai}, over the range 0.0156 to 0.156 lb./cu.ft.; but there is evidence that the relationship breaks down for more dilute gas.

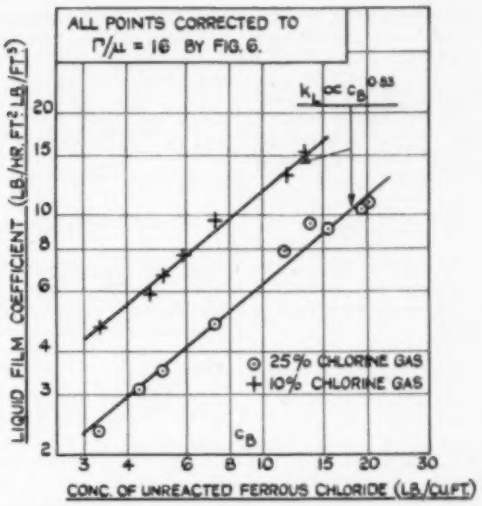
ALL POINTS CORRECTED TO
Γ/μ = 16 BY FIG. 6.
$k_L \propto c_B^{0.83}$
25% CHLORINE GAS
10% CHLORINE GAS
c_B
LIQUID FILM COEFFICIENT (LB./HR. FT.² LB./FT.³)
CONC. OF UNREACTED FERROUS CHLORIDE (LB./CU.FT.)

Fig. 8. Liquid-film coefficients for chlorine absorption in ferrous-ferric chloride solution. Effect of concentration of unreacted ferrous chloride (c_B).

Theoretical Discussion on Method of Correlation. Data plotted in Figures 8 and 9 suggest that the liquid-film coefficient is a function of the ratio c_B/c_{Ai}; this is to be expected if a rapid irreversible reaction occurs in a narrow zone within the liquid film and the rate of absorption is controlled by diffusion of the reactants. On this assumption it has been shown by Sherwood (*10*) that when a gas A reacts with a substance B in solution the rate of absorption is given, in terms of the elementary two-film theory, by the equation:

$$N_A = \frac{Hp_A + (D_B/D_A)c_B}{(x_L/D_A) + (H/k_G)} \quad \text{. . . lb. moles/(hr.)(sq.ft.)} \qquad (6)$$

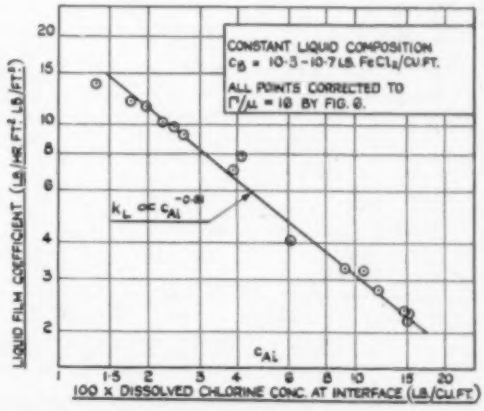
CONSTANT LIQUID COMPOSITION
c_B = 10·3 - 10·7 LB. $FeCl_2$/CU.FT.
ALL POINTS CORRECTED TO
Γ/μ = 16 BY FIG. 6.
$k_L \propto c_{Ai}^{-0.8}$
c_{Ai}
LIQUID FILM COEFFICIENT (LB./HR. FT.² LB./FT.³)
100 x DISSOLVED CHLORINE CONC. AT INTERFACE (LB./CU.FT.)

Fig. 9. Liquid-film coefficients for chlorine absorption in ferrous-ferric chloride solution: effect of gas composition.

Concentration of dissolved chlorine in ferric chloride solution at interface is used as variable, to eliminate deviations from Henry's law.

where x_L is the equivalent film thickness and D_A, D_B are the absolute diffusion coefficients of reactants A and B in the liquid.

In Equation (6) the term H/k_G can be eliminated by substituting for Hp_A the concentration c_{Ai} of dissolved gas (A) at the interface, so that the liquid film only is considered. Thus:

$$N_A = \frac{D_A}{x_L}\left[c_{Ai} + \frac{D_B c_B}{D_A}\right] \quad \text{. . . lb. mole/(hr.)(sq.ft.)}$$

or, dividing by the driving force, which is equal to c_{Ai} since there is assumed to be no free gas in the main body of the liquid:

Now D_A/x_L is by definition equal to the liquid-film coefficient for physical solution, so that Equation (7) can be written in the form

$$k_L = k_1[1 + k_2(c_B/c_{Ai})]$$
$$\text{. . . lb./(hr.)(sq.ft.)(lb./cu.ft.)} \qquad (8)$$

where k_1 is the coefficient for physical solution under similar conditions; and

$$k_L = \frac{D_A}{x_L}\left[1 + \frac{D_B}{D_A}\frac{c_B}{c_{Ai}}\right]$$

. . . lb. mole/(hr.)(sq.ft.)(lb. mole/cu.ft.) = lb./(hr.)(sq.ft.) lb./cu.ft.)

k_2 is the ratio of the diffusion coefficients of A and B, when the concentrations are expressed on a molar basis. If the concentrations used are in lb./cu.ft. as in the present work, k_2 involves also the ratio of the equivalent weights of the reactants.

Equation (8) is derived from the elementary two-film theory, which requires that for physical solution $k_L \propto D$; and for liquid flowing over packings it is known that $k_L \propto D^{0.5}$. If reaction occurs as assumed, therefore, the increase in the coefficient may not be linearly proportional to the ratio c_B/c_{Ai}, but may be expected to be a simple function of this ratio.

Now k_1 will be given by a dimensional expression of the form of Equation (2):

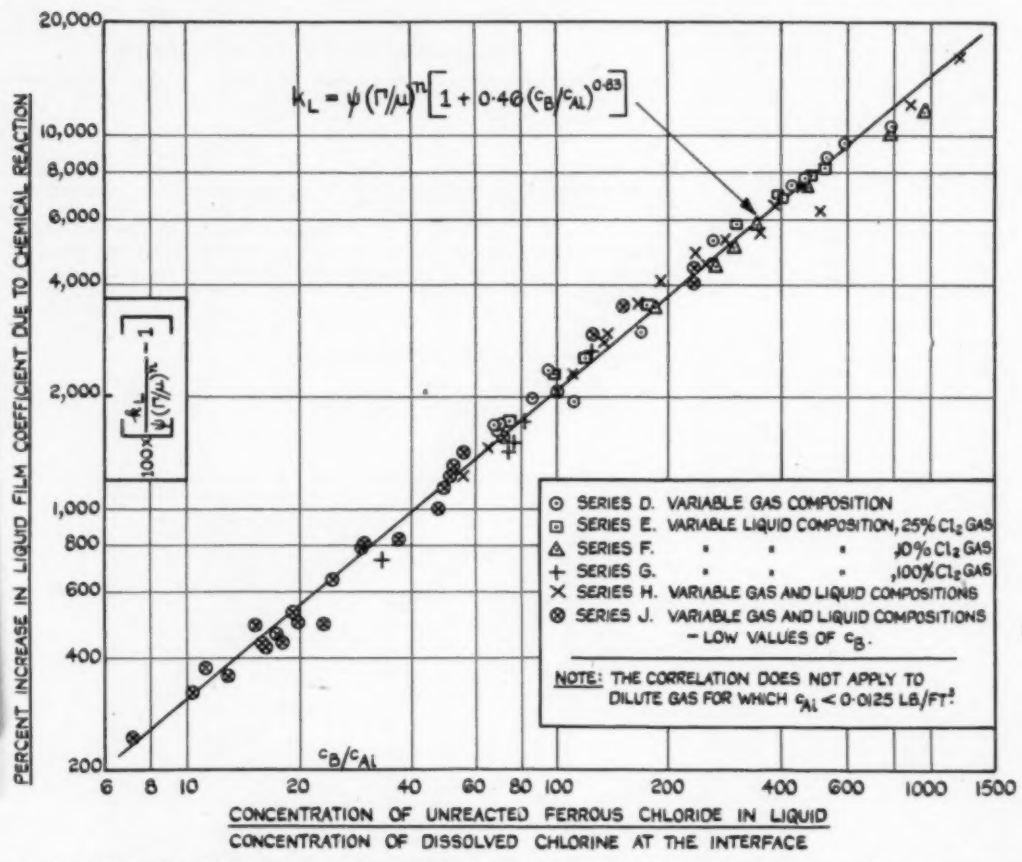

Fig. 10. General correlation of experiments on effect of gas and liquid composition for absorption of chlorine in ferrous-ferric chloride solution.

Notes: c_{Ai} = dissolved chlorine concentration at interface, assuming liquid here contains ferric chloride only (lb./cu.ft.)

c_B = concentration of ferrous chloride in the liquid (lb./cu.ft.), ($c_B = 0$ for fully chlorinated liquid, 28.7 lb. $FeCl_3$/cu.ft.)

i.e.,

$$\frac{k_1}{D} = a\left(\frac{\Gamma}{\mu}\right)^n \left(\frac{\mu}{\rho D}\right)^{0.5} \quad \ldots \text{ ft.}^{-1}$$

or

$$k_1 = a\left(\frac{\Gamma}{\mu}\right)^n \left(\frac{\mu D}{\rho}\right)^{0.5}$$

$\ldots$ lb./(hr.)(sq.ft.)(lb./cu.ft.)

This can be applied to the results of the chemical reaction experiments if allowance is made for the changes in physical properties of the liquid as conversion from ferrous to ferric chloride proceeds. For this purpose it will be assumed as a first approximation that the diffusion coefficient is affected only by the viscosity of the liquid (since the range of absolute temperatures in the experiments is small and $D \propto T/\mu$). Thus, since the density change is only of the order of 3%, the term $(\mu D/\rho)^{0.5}$ is practically constant. A sufficient allowance for changes in both liquid rate and physical properties of the liquid is therefore provided by the term (Γ/μ).

It is convenient to substitute for the group $a.(\mu D/\rho)^{0.5}$ a factor ψ, so that in an equation of the type of Equation (8):

$$k_1 = \psi(\Gamma/\mu)^n \quad \ldots \text{ ft./hr.}$$

The factor ψ can be evaluated from the experiments on physical solution in ferric chloride solution (Fig. 6) as follows:

(a) When

$\Gamma/\mu > 16, \psi = 1.87 \times 10^{-2}$ ft./hr. and $n = 0.7$

(b) When

$\Gamma/\mu < 16, \psi = 3.25 \times 10^{-2}$ ft./hr. and $n = 0.5$

If therefore the assumption that absorption is controlled by rates of diffusion is correct, a correlation of the results may be expected by plotting $[k_L/\psi(\Gamma/\mu)^n] - 1$ (which represents the increase in coefficient due to the chemical reaction) against (c_B/c_{A1}), using these values of ψ and n.

Correlation of Results. Results of six series of experiments in which the gas and liquid compositions were varied are plotted in the above-stated manner in Figure 10; runs are omitted for which c_{A1} is less than 0.0125 lb./cu.ft. (corresponding to about 7% chlorine in the gas at 20° C.) the results for which fall consistently low. A good correlation is obtained, the equation for which is:

$$k_L = \psi(\Gamma/\mu)^n[1 + 0.46(c_B/c_{A1})^{0.83}] \quad \ldots \text{ lb./(hr.)(sq.ft.)(lb./cu.ft.)} \qquad (9)$$

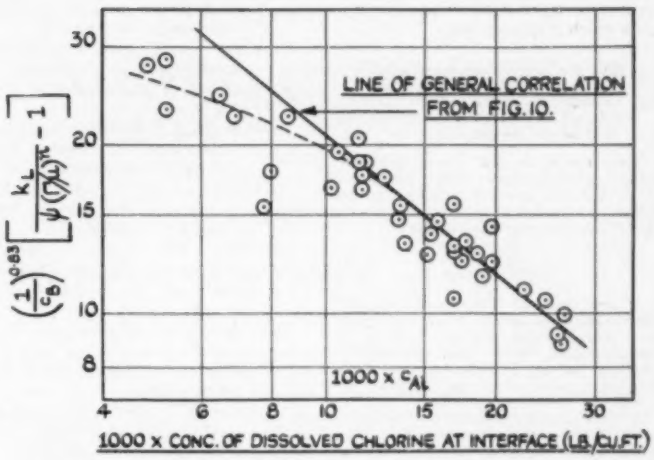
LINE OF GENERAL CORRELATION FROM FIG. 10.
$\left(\frac{1}{c_B}\right)^{0.83}\left[\frac{k_L}{\psi(\Gamma/\mu)^n} - 1\right]$
1000 x c_{A1}
1000 x CONC. OF DISSOLVED CHLORINE AT INTERFACE (LB./CU.FT.)

Fig. 11. Effect of gas composition: data for dilute gas mixtures.

To show deviation from general correlation when c_{A1} is less than 0.0125 lb./cu.ft.
Ordinates represent increase in coefficient due to chemical reaction at constant liquid composition of 1 lb. residual ferrous chloride/cu.ft.

Deviations which occur with dilute gas mixtures are seen in Figure 11, which has been constructed to show the effect of gas composition alone. The reason for this behavior is not understood. Theoretically the over-all coefficient should increase at low strength and high ferrous chloride content until absorption is limited by the gas film, but in these experiments the proportion of gas-film resistance was never more than a few per cent and this was allowed for in calculating the liquid-film coefficients.

As a further check on the correlation results of the experiments on the effect of liquid rate (Figs. 6 and 7) are shown in Figure 12 in the form of a plot of $k_L/[1 + 0.46(c_B/c_{A1})^{0.83}]$ against Γ/μ.

It is seen that the results of the three series with chemical reaction (Fig. 7) and those for physical solution (Fig. 6) are satisfactorily correlated.

Limitations of the Correlation. Experimental results reported here cannot be used to predict the coefficients for weaker liquors of substantially lower viscosity. A few experiments have been made with a liquor containing initially 5.4 lb./cu.ft. of ferrous chloride (end

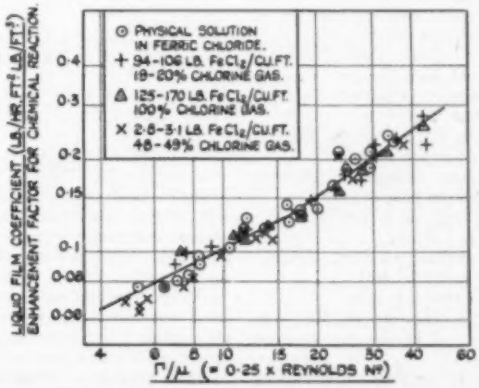
⊙ PHYSICAL SOLUTION IN FERRIC CHLORIDE.
+ 94-106 LB. $FeCl_2$/CU.FT. 19-20% CHLORINE GAS.
△ 125-170 LB. $FeCl_2$/CU.FT. 100% CHLORINE GAS.
× 2·8-3·1 LB. $FeCl_2$/CU.FT. 48-49% CHLORINE GAS.
LIQUID FILM COEFFICIENT (LB./HR.FT².LB./FT³) ENHANCEMENT FACTOR FOR CHEMICAL REACTION
Γ/μ (= 0·25 x REYNOLDS Nº)

Fig. 12. General correlation of experiments on effect of liquid rate at various gas and liquid compositions.

product 6.8 lb./cu.ft. of ferric chloride), from which it appears that:

1. Effect of liquid rate is negligible except at high degrees of conversion.
2. Coefficients increase with ferrous chloride concentration but do *not* depend on gas composition.

These results suggest that at the lower viscosity of these liquors (about 1.3-1.6 cps. at 20° C.) the reaction velocity can no longer be regarded as high compared with the diffusion rates of the reactants.

Conclusions

A new form of laboratory absorption column has been devised which has liquid-film characteristics similar to those of packed towers. It has been satisfactorily employed for the investigation of an absorption process involving chemical reaction.

It has been established that the absorption of chlorine in ferrous/ferric chloride solution (initially containing 23.5 lb. of ferrous chloride/cu.ft.) is controlled by the liquid film, and that the coefficients vary with liquid rate in the same way as for a physical solution process. Results are satisfactorily correlated on the assumption of a rapid reaction within the liquid film, the rate of absorption being controlled by the rates of diffusion of the reactants.

The correlation should not, however, be applied to weaker liquors of substantially lower viscosity.

Acknowledgments

The authors desire to acknowledge the collaboration of Messrs A. W. N. Brown and M. J. M. Raymond of I.C.I. Ltd., Billingham Division, in the development of the disc column; also of S. T. Glover of this department who carried out the experimental work described in the paper.

Notation

c_{Ai} = concentration of dissolved gas A at the gas/liquid interface, lb./cu.ft.

c_B = concentration of reactant B in solution, lb./cu.ft.

D = absolute diffusion coefficient, sq.ft./hr.

D_A = diffusion coefficient of A in liquid, sq.ft./hr.

D_B = diffusion coefficient of B in liquid, sq.ft./hr .

d = equivalent diameter for gas flow, ft.

H = Henry's law constant, lb./(cu. ft.)(atm.)

K_G = over-all absorption coefficient, lb./(hr.)(sq.ft.)(atm.)

k_G = gas-film coefficient, lb./(hr.)(sq.ft.)(atm.)

k_L = liquid-film coefficient, lb./(hr.)(sq.ft.)lb./cu.ft.

P = total pressure, atm.

p_A = partial pressure of dissolving gas A in the gas mixture, atm.

p_{Ai} = partial pressure of dissolving gas A at gas/liquid interface, atm.

p_{BM} = mean partial pressure of inert gas in gas film, atm.

v = gas velocity relative to liquid surface, ft./sec. or ft./hr.

x_L = equivalent film thickness (liquid film), ft.

α = empirical constant obtained by calibration of column, for liquid-film coefficient, $ft.^{-1}$

β = empirical factor obtained by calibration of column, for gas-film coefficient, —

Γ = liquid flow rate per unit width of surface, lb./(hr.)(ft.)

ρ = density of gas or liquid, lb./cu.ft.

ρ_d = density of diffusing gas, lb./cu.ft.

μ = viscosity of gas or liquid, lb. mass/ft.hr.

ψ = empirical factor used in correlation of experiments on chlorine-ferrous chloride system, ft./hr.

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Discussion

H. R. L. Streight (Canadian Industries, Ltd., Montreal, Canada): The authors designed a standard laboratory absorption tower which will give standard results without end effects as found in a wetted-wall column. Has there been any check on the size of the elements used in the described tower and if not, will this tower be taken as a standard and its coefficients compared with those obtained from standard packed towers. Have any correlations been made on the coefficients obtained under standard gas and liquid flows in the new tower compared with those obtained under similar conditions for standard packings?

G. A. Morris: We have not experimented at all with columns of this type with different-sized discs in them, but we have an extensive series of measurements on the carbon dioxide-water system for various commercial packings such as Raschig rings. We can use the results obtained on the laboratory column to predict the performance of these packings, which usually differ from those of the laboratory column by a factor in the range of 0.5 to 1. As has been mentioned it is, of course, necessary for the most accurate knowledge to calibrate the actual laboratory column used.

H. R. L. Streight: Could you amplify a little the meaning of the factor of 0.5 to 1?

G. A. Morris: The comparison is made at some fixed liquid rate, gamma. If the liquid-film coefficient is measured at a particular liquid rate in the laboratory, then the coefficient for the same liquid rate on the packing will vary from practically the same value down to half the laboratory figure, depending on the characteristics of the packing.

(Presented at Montreal (Que.) Meeting.)

LETTER TO THE EDITOR

NOTATION FOR LARGE AND SMALL NUMBERS

Sir:

I have read with interest Mr. Clegg's article in the January, 1951, number of Chemical Engineering Progress and the letter of R. Edgeworth Johnstone in the March issue regarding an abbreviated notation for large and small numbers. Apparently there is a real need for an abbreviated notation.

I have used a notation for the last thirty years which seems clearer than either of those proposed. It is not original with me but was picked up from one of the professors at M.I.T. many years ago. I do not remember which one.

To illustrate, 6.62×10^{-4} is written in my terminology as $6.72\backslash{-4}$, and 4.8×10^{3} is written as $4.8\backslash{3}$. The diagonal line, placed so its center is approximately level with the top of the numerals, means "times 10 to the nth power." In this notation, it is not necessary to memorize any details or rules regarding positive or negative signs. It is easily written and typed.

Ernest D. Wilson

Worcester, Mass.

VAPOR-PHASE CATALYTIC ESTERIFICATION RATES

R. A. BUCKLEY † and R. J. ALTPETER

University of Wisconsin, Madison, Wisconsin

An experimental investigation of reaction rates for the vapor-phase esterification of acetic acid and ethyl alcohol with a silica gel catalyst led to the conclusion that the reaction rate was limited by the rate at which acetic acid was activatedly adsorbed when the mole fraction of acetic acid in the feed was less than 0.7 at temperatures between 200° C. and 260° C. and under total pressures of 1 to 2.33 atms. The rate of adsorption of acetic acid was found to be dependent on the water content of the silica gel.

Applying the methods of Hougen and Watson, a reaction rate equation was established based on these conclusions. A function having the form of an adsorption isotherm related the partial pressure of water vapor in the reacting stream to the total number of active sites available for reaction. It is probable that the active sites were actually adsorbed water molecules. The integrated rate equation correlated data taken over a wide range of feed compositions at three temperatures and under three pressures.

The apparent over-all reaction velocity constant formed from the product of the effectiveness factor, reaction velocity constant for the activated adsorption of acetic acid and an equilibrium constant for the effect of water on the number of active sites, was found to be an approximately linear function of the reciprocal absolute temperature.

THE homogeneous esterification of acetic acid with ethyl alcohol in the gas phase has been found by others (*5,6*) to proceed at negligible rates, but the reaction is catalyzed by silica gel (*1,2*), thoria on silica or alumina (*3*), as well as xerogels and aerogels (*4*). Metallic oxides have also been found to catalyze the esterification of ethyl alcohol with benzoic acid (*13*). The only appreciable side reaction occurring at temperatures below 300° C. is the association of acetic acid into double molecules, while at 300° C. the dehydration of alcohol begins to occur at measurable rates.

Any reaction catalyzed by a solid surface must involve a sequence of steps including diffusion of reactants from the main gas stream up to the catalyst; diffusion into the pores of a porous catalyst; adsorption of at least one of the reactants; reaction on the catalyst surface, and desorption and diffusion of products into the main gas stream. The kinetics of many gas-phase reactions have been analyzed by assuming that one of these steps limits the reaction rate and that the rest proceed under equilibrium conditions. Methods for establishing the rate equation when the adsorption, desorption or surface reaction is rate-controlling have been advanced by Hougen and Watson (*7*). Transfer of products and reactants between the main stream and the external catalyst surface may be considered as mass transfer through a fluid film on the external surface of the catalyst in a flow system for which rates may be estimated using the correlation of mass- and heat-transfer numbers presented by Gamson, Thodos and Hougen (*8*) and by Wilke and Hougen (*14*). As yet, no general method has been developed for treating diffusion rates within the pore structure of a catalyst. However, for first-order reactions, Thiele's modulus (*12*) may be used to estimate the effect of diffusional gradients within the particle on the rate.

The objectives of the work reported here were the determination of the rate-controlling step for the esterification reaction, if it existed, and establishment of a rate equation based on this step which would correlate experimental conversion data.

Experimental Work. Experimental equipment was essentially that used by Hoerig, Hanson and Kowalke (*6*). A flow diagram of this equipment is presented in Figure 1. Liquid acetic acid and ethyl alcohol were pumped separately from calibrated feed burettes with a Hills-McCanna proportionating pump into an electrically heated vaporizer-preheater where they were separately vaporized and the vapors brought up to operating temperatures. The vapors were conducted through heated lines to the bottom of the reactor where they were mixed. The reactor was a 6-ft. long, jacketed, 2-in. stainless steel pipe heated by circulating Dowtherm through the jacket. The lower 18 in. of the reactor were kept free of catalyst to permit final adjustment of the temperature of the reaction mixture. The catalyst, consisting of 2431 g. (weight after 24 hrs. at 300° C.) of silica gel was supported on a perforated stainless steel plate. The product gases were condensed immediately in an ice-cooled stainless steel condenser. Heat input to the vaporizer and Dowtherm circulation system was controlled by micro switches operated by the expansion of silica rods in the aluminum block of the vaporizer and the jacket of the reactor. Temperatures were measured with chromel-alumel thermocouples located as shown in Figure 1.

The acetic acid reactant contained 0.002% of water by weight and the alcohol 0.006%. Water concentrations were determined by density measurement in both cases and in addition by titration with standard base for the acid. These checked closely the specifications of both acid and alcohol. These concentrations result: l in a mole fraction of water equal to 0.011 in an equimolal gas feed at the reactor entrance. Dilution of the feed was accomplished by adding water to the acid alone since this permitted closer determination of concentrations by titration with standard base.

Heated Dowtherm was circulated through the jacket of the reactor until the operating temperature range was reached. The temperature controller was then set to maintain the desired temperature as indicated by a thermocouple in the wall between the reactor and the jacket. The feed pump was started and the feed rate set by determining the time necessary for 50 ml. to be pumped from the burettes. For the next two hours, the unit was run

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A table titled "Experimental Results," with a corresponding notation is on file (Document 3182) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Material obtainable by remitting $1.00 for a microfilm and $1.00 for photocopies.

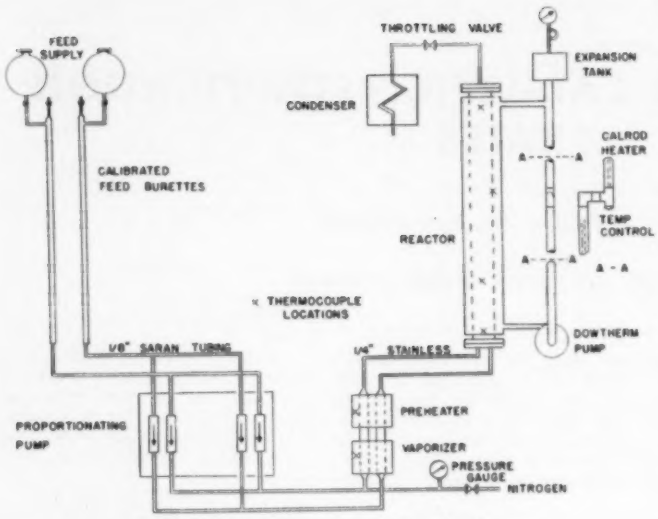

Fig. 1. Flow sheet of experimental unit.

without sampling the product and frequent readings were taken of feed rate and temperatures in the system including the inlet and outlet of the bed of gel. The maximum variation in temperature observed over the bed depth was 2.0° C. The product was then sampled at 15-min. intervals until steady-state conditions had been reached as indicated by constancy of the analysis of three consecutive samples. About 4 hrs. were required to complete a run after the feed pump had been started.

The comparatively small temperature drop over the length of the reactor resulted from a low reaction rate, a small value of ΔH for the reaction and good heat transfer to the Dowtherm. The enthalpy change for one mole of acetic acid reacting, ΔH, was calculated using Equation (7).

$$-\frac{\partial(\Delta G/T)}{\partial(1/T)} = \Delta H$$

$$= -4176 \text{ cal./g. mole}$$

Analysis of the product consisted of determining its density and titrating the unreacted acetic acid in a 1-ml. sample at 0° C. with 0.1 N sodium hydroxide. From the volumetric feed rate and density, the composition of the feed was determined and the percentage conversion of the alcohol and acid calculated. A sample calculation is shown in Table 1.

TABLE 1.—CALCULATIONS FOR RUN 84

Temperature of feed solutions (° C.)	19.0
Concentration of acid feed (wt. %)	99.8
Concentration of alcohol feed (wt. %)	99.4
Density of acid feed (g./ml.)	1.052
Density of alcohol feed (g./ml.)	0.791
Normality of standard sodium hydroxide solution	0.1209
Volume of titrant per gram of product (ml.)	36.3
Time required to pump 50 ml. of acid feed (hr.)	0.1485
Time required to pump 50 ml. of alcohol feed (hr.)	0.1450
Reactor temperature (° C.)	260.
Reactor pressure (atm. abs.)	2.33
Mass of catalyst (g.)	2431.
Cross sectional area of reactor (sq.ft.)	0.0218
Molecular weight of acetic acid	60.1
Molecular weight of ethyl alcohol	46.1

Basis: One hour of operation

G. moles of acid fed, $F_A = \frac{(50)(1.052)(.998)}{(.1485)(60.1)} = 5.88$

G. of solid/mole of acid fed, $W/F = \frac{(2431)}{(5.88)} = 413$

G. mole of alcohol fed, $F_B = \frac{(50)(.791)(.994)}{(.1450)(46.1)} = 5.87$

Moles of acid/mole of alcohol, $R = \frac{(5.88)}{(5.87)} = 1.001$

G. moles of unreacted acid/g. product $= \frac{(36.3)(.1209)}{(1000)} = 0.00438$

Weight of product, g. $= \frac{(50)(1.052)}{(.1485)} + \frac{(50)(.791)}{(.1450)} = 627$

Moles of unreacted acid $= (627)(.00438) = 2.74$

Fractional conversion of acid, $x = \frac{(5.88 - 2.74)}{(5.88)} = 0.533$

Mass velocity, lb./(hr.)(sq.ft.), $G = \frac{(627)}{(454)(.0218)} = 63.3$

Runs at elevated pressures were made by inserting a manually controlled throttling valve in the discharge line between the reactor and condenser. Pressure was measured with a Bourdon gauge calibrated against a dead-weight tester and placed in the alcohol feed line between pump and vaporizer.

Analysis of Initial Rate Data. It is convenient to represent kinetic data for a catalytic reaction by a series of curves representing conversion as a function of the reciprocal of the feed rate per unit weight of catalyst at constant temperature, pressure and feed composition. In Figures 5-9, the fractional conversion, x, of the limiting reactant is plotted against the reciprocal of the feed rate in gram moles of limiting reactant per gram of catalyst per hour, W/F. For an equimolal feed, it is immaterial which reactant is chosen as the basis for the curve. With coordinates defined in this fashion, the slope of these curves represents directly the reaction rate at which product is produced or reactant consumed in gram moles/(hr.)(gram of solid). By extrapolating these curves back to zero conversion (infinite space velocity) and studying the rates obtained by graphical differentiation at this point, it is frequently possible to draw some conclusions as to the nature of the reaction mechanism. Yang and Hougen (*15*) have discussed the analysis of initial rate data in detail.

The points on each of the curves of Figure 6 were established by determining the fractional conversion of acetic acid in an equimolal feed of acetic acid and ethyl alcohol with varying feed rates and constant catalyst mass, temperature (230° C.) and pressure (0.97, 1.65 and 2.33 atms.). All the points of Figure 5 were established at a constant temperature of 230° C. and pressure of 0.97 atms., but each curve represents a different mole ratio of reactants in the feed. Curves representing nominal ratios of 0.5, 1.0 and 2.0 moles of acetic acid to ethyl alcohol in the feed at 230° C. and 0.97 atms. were established first. Examination of the initial rates obtained by graphical differentiation of these curves (Fig. 2) indicated a linear relationship between the initial reaction rate and the partial pressure of acetic acid in the feed gas. This could be explained readily by assuming the activated adsorption of acetic acid to be the rate-controlling step, with the alcohol not adsorbed.

It can be shown (*9*) that the rate equation for activated adsorption of a reactant as the rate-controlling step where no adsorbed inerts are present is:

$$r = \frac{Ek_AL(a_A - a_Ra_S/a_RK)}{1 + K_A(a_Ra_S/a_RK) + K_Ba_B + K_Ra_R + K_Sa_S} \quad (1)$$

where:

r = reaction rate, gram moles/(gram solid)(hr.)
k_A = reaction velocity constant for adsorption of acetic acid
L = number of active sites, gram moles/gram
a = activities of acid (A), alcohol (B), water (R), and ester (S) at the gas solid interface based on unit fugacity
K_A, K_B, K_R, K_S = adsorption equilibrium constants for acetic acid, ethyl alcohol, water and ester respectively
K = equilibrium constant for the homogeneous reaction
E = effectiveness factor

If Equation (1) is applied to the initial rates when the amount of ester and water in the feed is negligible, the initial rate, r_o, becomes:

$$r_o = \frac{(Ek_AL)a_{AO}}{1 + K_Ba_{BO}} \qquad (2)$$

If it is further assumed that the alcohol reacts with adsorbed acetic acid by impact without adsorption itself, the initial rate becomes a linear function of the acetic acid activity at the interface:

$$r_o = (Ek_AL)a_{AO} = (Ek_AL)p_{AO} \qquad (3)$$

The factor (Ek_AL) is a constant at a fixed temperature and for a fixed particle size of the solid. Although the activities of Equation (1) are to be taken at the gas-solid interface, they are essentially equal to the main stream values. This point is discussed later. This linear dependence is in contrast with the effect observed with catalytic reactions in which the rate of surface reaction is controlling or with homogeneous second-order gas reactions where a maximum in the initial rate is observed with an approximately equimolal mixture.

The effect of pressure on the initial rate for an equimolal mixture was further evidence for activated adsorption being the rate-controlling step. At low pressures, the activity of acetic acid neglecting the slight effects of association is approximately:

$$a_A = N_AP$$

where:

N_A = mole fraction of acetic acid in the gas phase
P = total pressure, atms.

Applying Equation (1) to an equimolal feed assuming alcohol not to be adsorbed leads to the following expression for initial rate:

$$r_o = 0.5(Ek_AL)P \qquad (4)$$

This linear equation correlates the data of Figure 3.

It is apparent that the activated adsorption of one of the reactants cannot be rate-controlling over the whole range of reactant feed ratios, since increasing the concentration of the rate-controlling reactant must ultimately result in some other step becoming rate-controlling. In order to determine the range over which an activated adsorption rate-controlling mechanism could be assumed to apply, conversion curves consisting of two points at low values of W/F were established at acid-to-alcohol ratios of greater than 2 to 1. Initial rates obtained by graphical differentiation were plotted on Figure 2. These data indicated no shift in mechanism occurred until a mole fraction of 0.7 of acetic acid in the feed was reached. Since mole fractions higher than 0.7 are out of the practical range of economic interest, no attempt was made to correlate these data.

Effect of Water in Feed. Unless water or ester is introduced in the feed, the concentration of these two components will be identical in the reacting stream under steady-state conditions. To evaluate separately the constants K_R and K_S in Equation (1), it was necessary to get at least one conversion curve

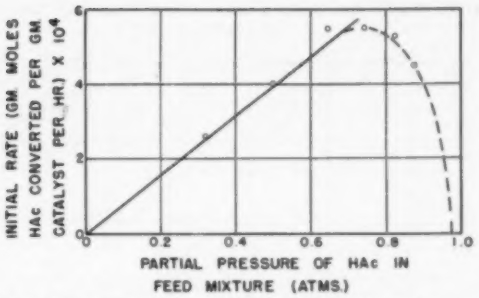

Fig. 2. Effect of feed composition on initial rate of reaction under a constant total pressure of 0.97 atm. at 230° C. No water was added to the feed. The curve is a plot of Eq. (5).

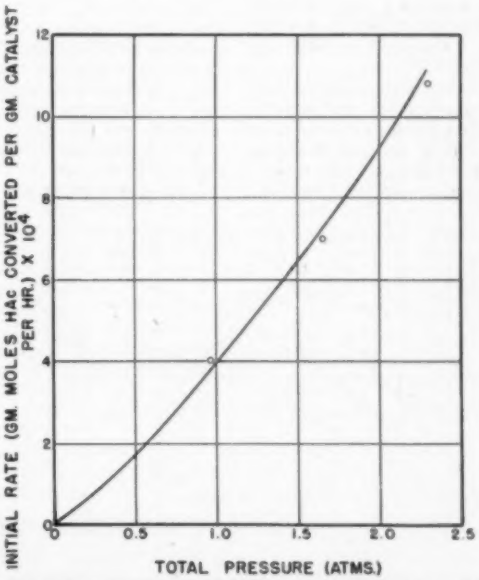

Fig. 3. Effect of total pressure on initial rate of reaction for an equimolal feed at 230° C. No water was added to the feed. The curve is a plot of Eq. (5).

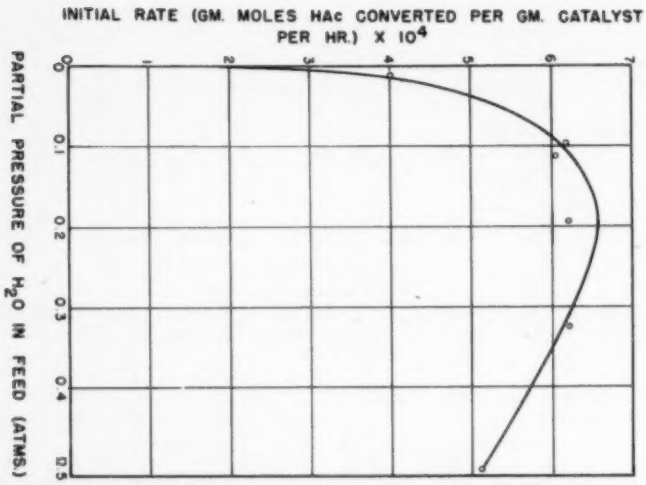

Fig. 4. Effect of addition of water to the feed on initial rate of reaction at a constant total pressure of 0.97 atm. at 230° C. The feed was equimolal with respect to acid and alcohol, but concentration of these two components was reduced as water was added to the feed. The curve is a plot of Eq. (5).

with water introduced in the feed in order to vary independently the activities of the two products. It was found that the addition of one mole of water per mole of acetic acid in an equimolal feed resulted in a sharp increase in the initial rate of reaction. In order to isolate the effect of water on the reaction rate, a series of conversion curves (Fig. 7) was established with varying amounts of water in an equimolal feed of acid and alcohol at 230° C. and 0.97 atms. The initial rates obtained are plotted in Figure 4.

Figure 4 indicates that small amounts of water markedly affect catalyst activity. This effect has been observed also with hydrocarbon reactions involving gel catalysts. In the case of the esterification reaction, an additional complication was present since water was formed by the reaction which led to varying catalyst activities through the catalyst bed.

Correlation of Initial Rate Data. As a step in the establishment of a rate equation which could be integrated to give the conversion curves of Figures 5-9, a correlation of the initial rate data of Figures 2-4 was developed. On the hypothesis that the number of active sites on the catalyst was a function of the amount of water adsorbed and that adsorption equilibrium existed with respect to water, it was thought that the term L in Equation (1) might be replaced by a Langmuir or Freundlich adsorption isotherm for water. This proved to be the case, and a satisfactory correlation was obtained when L was taken as proportional to $(a_{BO})^{0.275}$. The curves of Figures 2-4 are a plot of:

$$r_O = (Ek_A m)a_{AO}(a_{BO})^{0.275} \quad (5)$$

where:

$$L = m(a_{BO})^{0.275}$$
$$Ek_A m = 26.6 \times 10^{-4} \text{ at } 230^\circ \text{ C.}$$
$$m = \text{constant}$$

It should be emphasized that the conclusions arrived at in this paper are based on the correlation of the integral conversion data and not on this correlation of the initial rate data (Eq. (5)) which was established only as a guide for selecting the form of the final correlation.

The work of Pearce and Alvarado (*11*) on the adsorption of water, ethyl alcohol, acetic acid and ethyl acetate on aluminum oxide provides additional support for the reaction mechanism proposed here. In establishing the individual equilibrium adsorption isotherms of each of the components, they were able to get reproducible results with all but the acetic acid. Repeated trials on one sample of adsorbent resulted in decreasing amounts of acetic acid adsorbed as the moisture content of the adsorbent was progressively reduced. If, as the reaction rate data indicate, the adsorption of acetic acid is the rate-controlling step, Pearce and Alvarado's results would lead one to expect an increase in the reaction rate as the partial pressure of water in the reaction stream is increased. This is in agreement with the results obtained in the present investigation.

Correlation of Conversion Data. Equation (5) is a particular application of Equation (1) to initial rate data. In order to develop a correlation of all the conversion data, it remained to evaluate the constants, K_A, K_B and K_g in Equation (1). Since the process of graphical differentiation is subject to large errors, selection of these constants and the final form of the water adsorption relation was based on numerical integration of the rate equation. Equation (5) was numerically integrated to give conversion curves corresponding to those of Figures 4-6. The integration performed was:

$$W/F = \int_O^x \frac{dx'}{r(x')}$$

Based on the results of this integration, the equation was modified, and the modified equation was checked again by integration. Since it was necessary to re-establish the effect of water by this trial-and-error procedure, analytical integration of the rate equation was not possible. For each of 11 curves 40 such

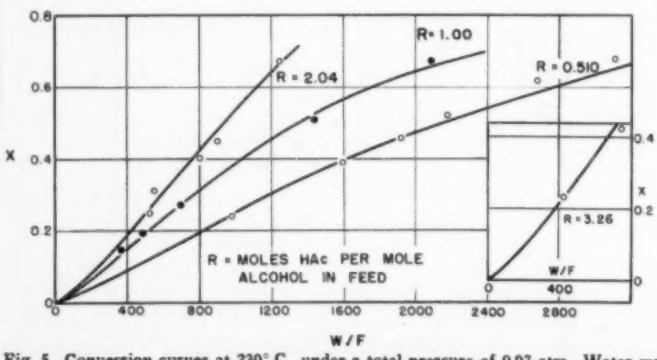

Fig. 5. Conversion curves at 230° C. under a total pressure of 0.97 atm. Water was not introduced into feed. Data for an equimolal feed under these conditions appears in Fig. 6 also. Curves shown result from the numerical integration of Eq. (6).

trials were necessary to establish the final equation at 230° C. which follows:

$$r = \frac{Ek_A m f(a_R)(a_A - a_R a_B/a_R K)}{1 + K_B a_B} \qquad (6)$$

where:

K = 15.30 at 230° C.
K_B = 1.5 at 230° C.
$Ek_A m$ = 34.31×10^{-4} at 230° C.
$f(a_R)$ = function representing effect of water on rate of adsorption of acetic acid
$f(a_R) = 0.798(a_R)^{0.320}$, $(a_R \leqslant 0.15)$
$= 0.300 + 0.900 a_R$, $(a_R \geqslant 0.15)$
m = equilibrium constant for the adsorption of water

The number of active sites, L, in Equation (1) was replaced by $mf(a_R)$ in arriving at Equation (6). The curves of Figures 4-6 were obtained by numerical integration of Equation (6). It can be seen from these curves that the formation of water as the feed enters the bed results in an increase in rate over a short depth of the bed. Hence, rates obtained by graphical differentiation of an arbitrary curve drawn through the experimental points and extrapolated to zero conversion are inaccurate. This accounts for the difference in the factor representing the effect of water between Equations (5) and (6).

The value of the equilibrium constant, K, used in Equation (6) was calculated from:

$$\Delta G^\circ = -4175.6 + 2.88T \qquad (7)$$

$$\Delta G^\circ = -RT \ln_e K \qquad (8)$$

where:

T = absolute temperature, ° K.
K = equilibrium constant defined in terms of activities based on unit fugacity

Equation (7) was developed by Knox and Burbridge (*10*) from a survey of the existing equilibrium data for this system.

In calculating the activities in Equation (6), account was taken of the association of acetic acid into double molecules which was assumed to be at equilibrium. Values of the equilibrium constant for the association reaction,

$$2\,HAc \rightleftharpoons (HAc)_2$$

were determined by Essex and Clarke (*2*) at three temperatures from P-V-T data in the International Critical Tables. Applying Kirchhoff's equation to their results, they arrived at the following expression for the association equilibrium constant, K_a, as a function of temperature:

$$K_a = \frac{17.0831}{T} + 29.12 \log_{10} T - 95.653 \qquad (9)$$

where:

T = absolute temperature, ° K.

Values of K_a from Equation (9) were used in calculating activities for Equation (6).

It was found that the value of K_A in Equation (1) had to be taken as zero in order to fit the conversion data. This is in agreement with the proposed rate mechanism since K_A will be small if the adsorption of acetic acid is the rate-controlling step. Since it was assumed that adsorbed water increased the number of active sites on the solid, the value of K_B in Equation (1) was taken as zero. This is reasonable, since the terms in the denominator of Equation (1) represent the hindering effect on the reaction due to the reduction in the number of active sites caused by adsorbed material. It is probable that the active sites in this case were actually adsorbed water molecules.

An interesting feature of all the conversion curves is the comparatively slow rate at which the velocity of the reaction falls off with increasing conversion. Any postulated driving force for the reaction which depends on the product of the activities of both reactants causes the rate to fall off much more rapidly.

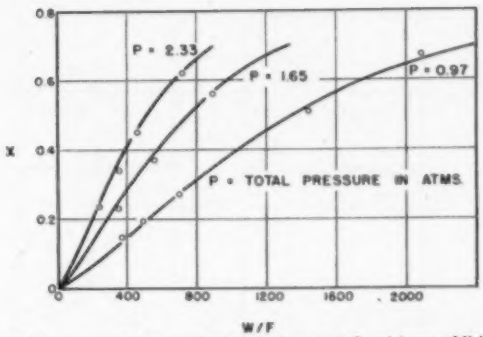

Fig. 6. Conversion curves for an equimolal feed at 230° C. without addition of water to feed. The curves result from numerical integration of Eq. (6).

Values of the activities of the components as a function of the conversion, x, for an equimolal feed at 200° C. and 1.65 atms. taking account of the association of the acetic acid are listed in Table 2. The numerical integration of the rate equation using these values is shown in Table 3. The resulting curve is plotted in Figure 8.

Catalyst Activity. In order to check the constancy of the catalyst activity, runs 11, 38, and 68 (total runs, 85) were made at a low value of W/F (approximately 450) on an equimolal mixture at 230° C. and 0.97 atms. At this low value of W/F, the conversion curves are essentially linear and the results are best compared on the basis of the value of $(x)/(W/F)$. Results obtained are shown in Table 4. Since the values shown in Table 4 are within the range of experimental precision, it was concluded that the catalyst activity was essentially constant. In a previous investigation, Hanson, Hoerig and Kowalke (*6*) found some loss of activity with time as decomposition products accumulated in the catalyst. They were able to regenerate their catalyst by heating at 300° C. for 15 hrs. In order to circumvent that difficulty in the present work, the catalyst was degassed at operating temperatures with nitrogen after each run.

Temperature Coefficient. A sound theoretical analysis of the effect of tem-

TABLE 2.—ACTIVITIES AT 200° C. AND 1.65 ATMS. FOR AN EQUIMOLAL FEED

x	a_{A1}	a_A	a_B	a_R	a_D	a_T	a_1	a_2	a_3	a_4	$a_{mol}/a_4 K$
0.0	.1096	.7808	1.0000	.0222	.0000	1.9126	.7636	.8627	.0192	.0000	.0000
0.1	.0917	.7166	0.9000	.1222	.1000	1.9305	.6125	.7692	.1044	.0855	.0006
0.2	.0750	.6500	0.8000	.2222	.2000	1.9472	.5508	.6779	.1883	.1695	.0024
0.3	.0595	.5810	0.7000	.3222	.3000	1.9629	.4884	.5884	.2704	.2532	.0058
0.4	.0454	.5092	0.6000	.4222	.4000	1.9768	.4250	.5008	.3524	.3339	.0118
0.5	.0329	.4342	0.5000	.5222	.5000	1.9893	.3601	.4147	.4331	.4147	.0217
0.6	.0221	.3558	0.4000	.6222	.6000	2.0001	.2935	.3300	.5133	.4950	.0386
0.7	.0130	.2740	0.3000	.7222	.7000	2.0092	.2250	.2464	.5931	.5749	.0694

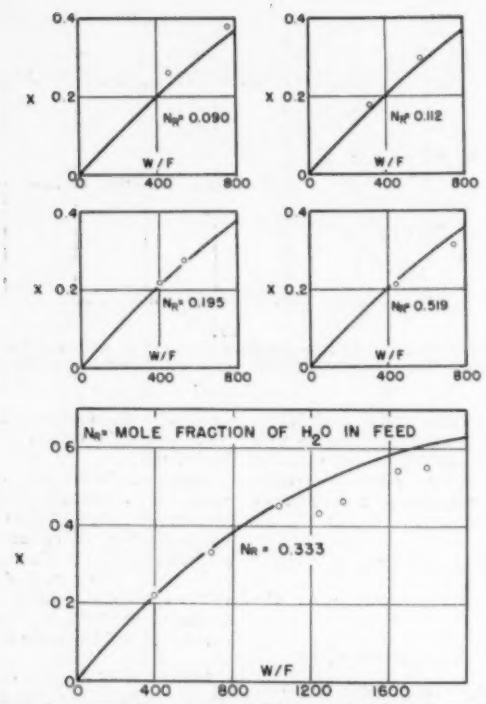

Fig. 7. Conversion curves for an equimolal feed at 230° C. under a total pressure of 0.97 atm. Varying amounts of water were introduced in the feed reducing the concentration of the reactants. The curves result from integration of Eq. (6).

perature on the reaction rate equation (Eq. (6)) is impossible without independent knowledge of the effect of temperature on the function, $f(a_R)$. Since it was shown that a correlation of the conversion data at 230° C. was achieved if the number of active sites, L, was represented by the equation:

$$L = mf(a_R)$$

it would be expected that L would be temperature-sensitive. Therefore in Equation (6), the following factors were functions of temperature: $mf(a_R)$, k_A, E, K and K_B. A satisfactory temperature correlation of the conversion data was obtained under the following conditions:

1. It was assumed that temperature affected only m in the factor $mf(a_R)$, and that m was essentially an equilibrium constant for which the temperature effect could be represented by the equation:

$$m = B' \exp(-\Delta H_B/RT) \qquad (10)$$

where:

B' = constant
ΔH_B = enthalpy change for the adsorption of water vapor, cal./g. mole
R = gas law constant, cal./(g. mole)(° K.)
T = absolute temperature, ° K.

2. The constant, k_A, was a reaction velocity constant for the activated adsorption of acetic acid and could be represented by Arrhenius' equation. Thus:

$$k_A = A' \exp(-\Delta H_A^{\ddagger}/RT) \qquad (11)$$

where:

A' = constant
$\Delta H_A^{\ddagger}$ = enthalpy of activation for activated adsorption of acetic acid

3. The effect of temperature on E is complex and depends in general on the effect of temperature on the other constants and on the effect of temperature on the diffusivity of acetic acid in the reacting system. However, the change with temperature of E becomes negligible as E approaches 1. The effectiveness factor was probably close to 1 during the present investigation as will be discussed. E was therefore considered constant with respect to temperature over the temperature range covered.

4. The effect of temperature on the equilibrium constant, K, was obtained from Equations (7) and (8).

5. The shape of the curves representing the integrated rate equation was insensitive to small changes in the value of the constant, K_B. Hence, it was not possible to detect any effect of temperature on K_B by the procedure of trial integrations used to establish the constant Ek_Am at the temperatures used.

In calculating the activities of the acetic acid, account was taken of the effect of temperature on the association equilibrium constant, K_p, with Equation (9).

After repeated trial integrations, the values of Table 5 were established for the constants (Ek_Am) and K_B at 200° C. and at 260° C.

The curves resulting from the integration of Equation (6) at 200° C. and 260° C. with the constants of Table 5 are shown in Figure 8 (200° C.) and Figure 9 (260° C.).

Combining Equations (10) and (11):

$$Ek_Am = EA'B' \exp\{(-H_R - H_A)/RT\} \qquad (12)$$

TABLE 3.—NUMERICAL INTEGRATION OF RATE EQUATION AT 200° C. AND 1.65 ATMS. FOR AN EQUIMOLAL FEED

$$W/F = \int_0^x dx/r$$

$$r = \frac{25.94 \times 10^{-4} f(a_R)(a_A - a_R a_S/a_R K)}{1 + 1.5\ a_S}$$

Let $D(a_A)$ represent the driving force in the rate equation.

x	a_S	$f(a_R)$	$D(a_A)$	fD	Num.	a_S	Denom.
0.0	.0192	.1923	.6736	.1295	3.359	.0000	1.0000
0.1	.1044	.3814	.6119	.2334	6.054	.0855	1.1283
0.2	.1883	.4695	.5484	.2575	6.680	.1695	1.2543
0.3	.2708	.5437	.4826	.2634	6.807	.2522	1.3783
0.4	.3524	.6172	.4132	.2550	6.615	.3339	1.5009
0.5	.4331	.6898	.3384	.2334	6.054	.4147	1.6221
0.6	.5129	.7620	.2549	.1942	5.038	.4950	1.7425
0.7	.5931	.8338	.1556	.1297	3.364	.5749	1.8624

x	$1/r$	$(1/r)_{av}$	W/F
0.0	2977	2420	0
0.1	1863	1871	242
0.2	1878	1952	429
0.3	2025	2146	624
0.4	2268	2473	839
0.5	2679	3069	1086
0.6	3458	4497	1393
0.7	5536		1843

Values of a_R, a_S and $D(a_A)$ were obtained from Table 2. The value of $f(a_R)$ as a function of a_R can be found in Fig. 10.

TABLE 4.—CONSTANCY OF CATALYST ACTIVITY

Run No.	W/F	x	$(x)/(W/F)$
11	491	.197	4.01×10^{-4}
38	449	.194	4.32×10^{-4}
68	447	.186	4.16×10^{-4}

TABLE 5.—CONSTANTS IN THE RATE EQUATION

T, ° C.	Ek_Am	K_B	K
200	25.94×10^{-4}	1.5	19.93
230	34.31×10^{-4}	1.5	15.30
260	53.37×10^{-4}	1.5	12.09

A correlation of the temperature effect on the constant (Ek_Am) with Equation (12) is found in Figure 11. Values obtained for the constants were:

$$EA'B' = 1.203 \times 10^{-4}$$

$$(\Delta H_B + \Delta H_A^3) = 5800 \text{ cal./g.mole}$$

The function $f(a_B)$ seems well established since it enters into all 17 conversion curves plotted. These curves cover a wide range of feed compositions and conversions as well as three temperatures and pressures. This function is plotted in Figure 10. The similarity to an adsorption isotherm is apparent.

Other Mechanisms. In some catalytic reactions proceeding at relatively high rates, the resistance to transfer of products and reactants from the main gas stream to the surface of the catalyst particles reduces the over-all rate of reaction. Using the correlation of mass- and heat-transfer numbers given by Gamson, Thodos and Hougen (*8*) and by Wilke and Hougen (*14*), the partial pressure gradients of reactants and products from the main gas stream to the external surface of the catalyst in a flow system may be estimated. In order to determine whether a diffusion step was influencing reaction rates obtained, the diffusional gradient of acetic acid was estimated using the maximum rate determined by graphical differentiation, 4.01×10^{-4} gram moles/ (gram solid) (hr.), and the minimum mass velocity used, 8 lbs./(hr.)(sq.ft.), in establishing the curve at 230° C. and 0.97 atms. for an equimolal mixture. It was found that the gradient was only 0.0018 times the value of the partial pressure of acetic acid. Since this is negligible, it was permissible to neglect diffusional gradients due to mass transfer across the external film. Under these conditions, it was not necessary to maintain a constant mass velocity while varying space velocity. Therefore, the space velocity was varied by varying the feed rate with a constant mass of catalyst. The small gradient calculated results from a comparatively low rate of reaction.

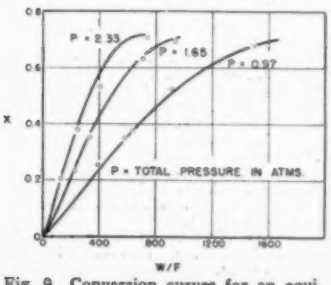

Fig. 9. Conversion curves for an equimolal feed at 260° C. without addition of water to feed. The curves result from the numerical integration of Eq. (6).

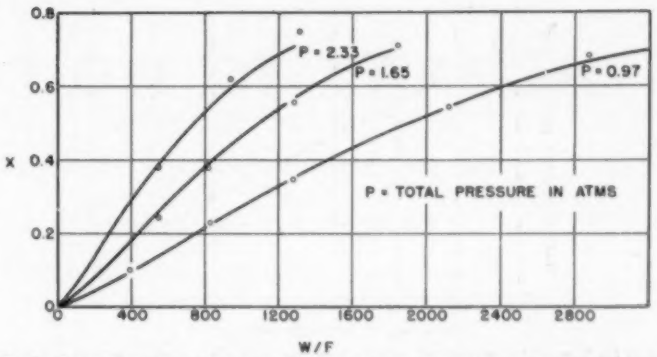

Fig. 8. Conversion curves for an equimolal feed at 200° C. without addition of water to the feed. The curves result from the numerical integration of Eq. (6).

Hanson, Hoerig and Kowalke (*6*) working with this same system decided that a diffusional step within the catalyst particle was rate-controlling. They proposed the following mechanism equation:

$$K_L V_R = \int_{n_{p1}}^{n_{p2}} \frac{dn_p}{y_{ag} - y_{ae}}$$

where:

n_p = moles of product formed per hour
V_R = volume of reaction chamber
y_{ag} = mole fraction of component a in gas stream
y_{ae} = mole fraction of a at equilibrium
K_L = mass-transfer coefficient

Using this equation, they were able to calculate by graphical integration values of K_L from individual runs which were constant for data taken at 1 atm. with an equimolal feed. Considerable variations in K_L were observed when it was attempted to apply this equation to other than equimolal mixtures, while data at pressures other than one atmosphere were not taken.

Since the diffusional properties of ethyl alcohol and acetic acid are similar, a maximum initial rate at constant pressure and temperature would be expected with an approximately equimolal feed. Since the maximum rate was observed at a mole fraction of acetic acid of about 0.7 (Fig. 2), it seems unlikely that a diffusion step was rate-controlling. Nor could a diffusion mechanism explain the increase in rate observed when the reactants were diluted with water.

It is frequently observed in catalytic reactions that with all other variables held constant there will be a decrease in rate as the catalyst particle diameter is increased. This effect, due to the greater accessibility of the external surface for reaction, is a diffusional phenomenon and is usually minimized by operating with a single particle size. In the present work, only catalyst particles in the four-to-six mesh range were used. Data of Hanson, Hoerig and Kowalke (*6*) demonstrating this effect for the esterification reaction indicate that diffusion within the particle does affect the rate if particle size is varied but do not imply necessarily that this is the rate-controlling step, if the diffusional effect is minimized by operating always with the same particle size. It was found that Thiele's method (*12*) of relating effectiveness factor data gave an excellent correlation of Hanson's data. Given the effectiveness factor for any two particle sizes, it is possible to predict the effectiveness factor for a third particle size with Thiele's modulus. Following this procedure, the predicted catalyst effectiveness factor differed from the experimental by only 1%. Since Thiele's method applies rigorously only to first-order reactions where the rate is proportional to the first power of the concentration at the interface, a

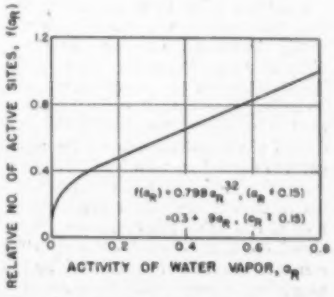

Fig. 10. An illustrative plot of the function $f(a_B)$ representing effect of water on catalyst activity. The activity of the water vapor, a_B, is based on unit fugacity.

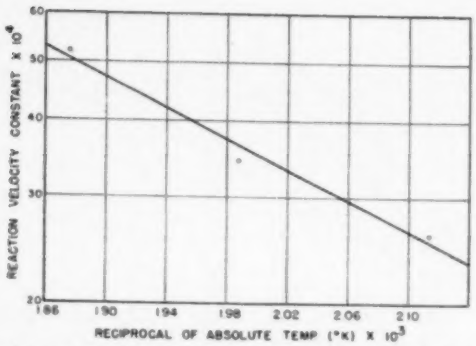

Fig. 11. The apparent reaction velocity constant (Ek_Am) is plotted against reciprocal absolute temperature. The constants of Eq. (12) were derived from the curve.

good correlation of the initial rate esterification data would be expected when the activated adsorption of acetic acid is the rate-controlling step.

The catalyst used in the present investigation showed activities considerably lower than those of the catalyst used by Hanson for particles of equal size under identical operating conditions. However, it was possible to reproduce their results with a small amount of their catalyst which was available. On the single run made with their catalyst at 230° C., 0.97 atms., equimolal feed, six-to-eight mesh particle size, a fractional conversion of 0.294 was obtained at W/F equal to 120. The value predicted from a curve joining their experimental points was 0.307.

The relatively low initial rates observed here, 2.71×10^{-4} g.moles/(g. catalyst)(hr.) for a 1:1 mixture at 230° C. and 0.97 atms. calculated from Equation (6), make it seem unlikely that a diffusion mechanism could control the rate. The fact that diffusion across the external film had no effect on rate at low mass velocities, 8 lbs./(hr.)(sq. ft.), is further evidence that diffusional gradients within the catalyst were not likely to have been large.

Although it has been well established that the homogeneous reaction rate is negligible (*5, 6*), there was the possibility that reaction could occur in the liquid phase while condensation was occurring even though an ice bath was used to insure rapid cooling of the condensed phase and titration of the product was carried on with ice in the flask. Accordingly, two runs were made without catalyst in the reactor duplicating a normal run in all other respects. Fractional conversions of 0.002 and 0.005 were observed. This is easily within the range of experimental precision and checks the results of Hanson, Hoerig and Kowalke (*6*) who found a conversion of less than 0.01 using the same technique.

It was felt at one time that the increase in rate resulting from the introduction of water in the feed might be caused by an increase of acetic acid activities by dilution of a condensed liquid phase within the catalyst. While it was not possible to set up a critical experiment to dispose of this hypothesis, the linear relationships between initial rate and pressure and between initial rate and mole fraction of acetic acid in the feed make this seem unlikely. The best evidence for the adsorption mechanism proposed here is, of course, the good fit of Equation (6) to data taken over a wide range of experimental conditions.

Acknowledgments

The authors wish to acknowledge the financial support received from the Du Pont Co., and the helpful advice received from O. A. Hougen and K. M. Watson.

Notation

a = activity based on unit fugacity
E = effectiveness factor equal to rate at which reaction proceeds, divided by rate at which it would proceed if the internal surface of the catalyst were as accessible to reactants as the external surface
F = feed rate of the limiting reactant, g.moles/hr.
G = mass velocity, lbs./(hr.)(sq. ft.)
H = enthalpy, cal./g.mole
$H\ddagger$ = enthalpy of activation, cal./g. mole
K = equilibrium constant for the gaseous esterification reaction
K_a = equilibrium constant for association of acetic acid into double molecules
K_A = equilibrium constant for activated adsorption of acetic acid (similarly for other components)
K_L = mass-transfer coefficient (units undefined)
k = reaction velocity constant
L = number of active sites, g.moles /g.
m = equilibrium constant for adsorption of water vapor
N = mole fraction
n = number of moles, g. moles
P = total pressure, atm.
p = partial pressure, atm.
R = molal ratio of acid to alcohol in the feed
r = reaction rate, g. moles/(g. solid)(hr.)
V_R = reactor volume (units undefined)
W = mass of catalyst, g.
x = fractional conversion of limiting reactant

SUBSCRIPTS:

$_A$ = acetic acid
$_{2A}$ = double molecules of acetic acid
$_B$ = ethyl alcohol
$_R$ = water
$_E$ = ethyl acetate
$_T$ = total moles
$_0$ = initial conditions

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(*Presented at Minneapolis (Minn.) Meeting.*)

GASIFICATION OF CARBON

Metal Oxides in a Fluidized Powder Bed

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MANY industrially important processes involve the transfer of oxygen from one material to another. When both reactants and products include fixed gases, separation of the desired products may be quite costly. The metal oxide "oxygen-carrier" technique has been proposed in certain oxidation reactions to sidestep this difficulty. For example, with air as the oxidizing gas, carbon dioxide is produced from carbon, carbon monoxide and hydrogen mixtures from methane, and sulfur dioxide from sulfur. If the oxidation is performed directly, the gaseous products are diluted with great quantities of nitrogen, whereas, with an oxygen carrier, the oxygen may be taken from the air by the solid and in a separate step given up to the reaction raw material. Previous investigators (*8, 9*) using this technique have studied the following reactions:

$$CH_4 + CuO \rightarrow CO + 2H_2 + Cu \quad (1)$$

$$FeS + 10Fe_2O_3 \rightarrow 7Fe_3O_4 + SO_2 \quad (2)$$

In the present investigation, it was desired to study the possibilities of the production of carbon dioxide from carbon by this oxygen-carrier technique. If such a process were operable, it would eliminate the usual absorption step in the production of carbon dioxide.

In choosing a suitable metal oxide, in addition to the necessities of low cost, high melting and softening points, nontoxicity, noncorrosiveness, etc., the primary requirements for a suitable metal oxide are being thermodynamically capable of oxidizing carbon and carbon monoxide to carbon dioxide and, at the same time, being capable of regeneration by air at temperatures approximately equal to those necessary for the reaction. On the basis of these requirements, it was concluded that some of the oxides of cobalt, nickel, manganese, iron, and copper were the most suitable. Ferric oxide and cupric oxide, being approximately at opposite ends of the permissible thermodynamic scale, were those chosen for study.

Because the reaction of two solids would be involved, plus frequent regeneration of the metal oxide, a continuous operation would be desirable. For large-scale operation this continuous operation with solids can be obtained by either the fluidized powder or moving-bed techniques. In order to simulate industrial operation, and in order to gain the advantages of uniform reaction temperature, the experimental program was carried out in fluidized powder beds.

Experimental Procedure

Apparatus and Procedure. The primary investigation was carried out in a fluidized powder bed in which part of the product gas was rapidly recirculated back to the inlet to provide fluidization and to obtain a uniform reactor gas composition. The runs were batchwise with respect to the carbon and the oxide. The weighed quantity of carbon was blown into the oxide already fluidized in carbon dioxide at the reaction temperature. A diagrammatic sketch of the reactor giving pertinent dimensions is shown in Figure 1 and a flow sheet of the system is given in Figure 2.

The measured rate of reaction was the rate of gas passing out through the wet test meter or continuous analyzer from this constant pressure, constant volume closed system. The system was originally charged and purged with carbon dioxide from a commercial gas cylinder but after the run was initiated no additional carbon dioxide was supplied and the fluidization was carried out by the recycle of the gas within the system. By the application of carbon and oxygen material balance equations

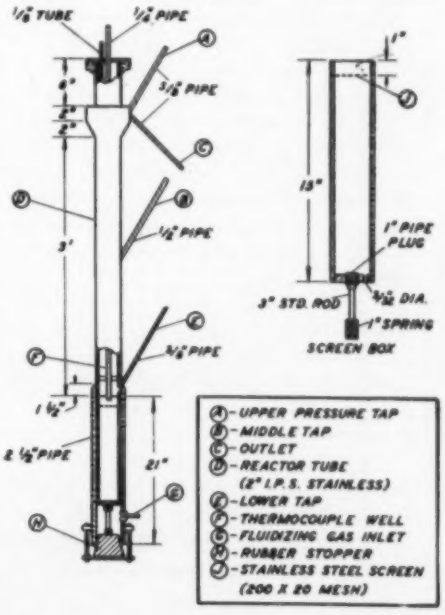

Fig. 1. Reactor design.

Complete information on all the runs is on file (Document 3185) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Obtainable by remitting $1.00 for a microfilm and $1.00 for a photocopy. Also a copy of M. P. Sweeney's Sc.D. thesis can be borrowed from the chemical engineering department, M.I.T.

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over short-time intervals, on the assumption that the reactor gas composition was uniform and equal to the exit composition (i.e., at the continuous analyzer), the rate of gasification of the carbon and the rate of reduction of the oxide, respectively, were obtained. The total amounts gasified were calculated by summing the incremental values. Typical results are shown in Figures 3-8 and in Table 1. Additional data are available in the theses of Duerr (2) and Harris and Honnold (7).

The reactor gas, mainly carbon dioxide, was continuously analyzed by withdrawing a small gas stream at a measured rate, absorbing the carbon dioxide from it by potassium hydroxide solution and ascarite, and measuring the resulting caustic-insoluble tail gas rate. The tail gas was collected and analyzed by the precision Orsat technique.

TABLE A

Volatile Combustible Matter (VCM)	Ash	Carbon	Hydrogen	Nitrogen	Sulfur
2.45	9.80	88.25	0.75	0.84	0.74

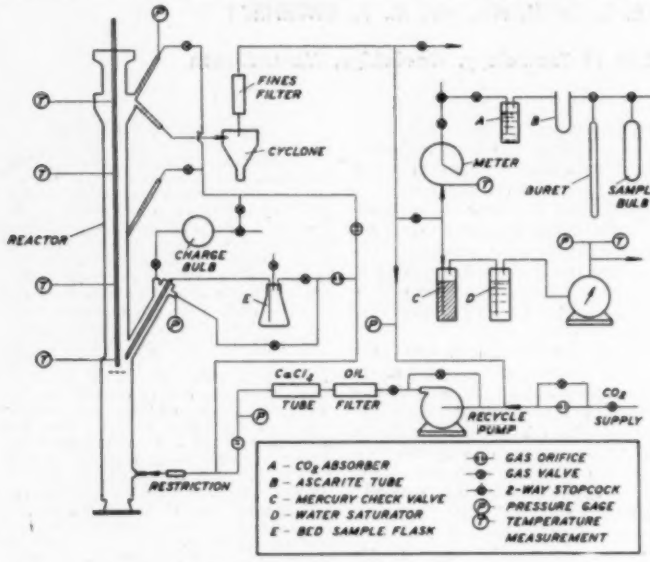

Fig. 2. Schematic diagram of apparatus.

Reaction Materials

a. *Iron Ore.* The ore used in this investigation was a sample of Lake Superior hematitic ore from the pits of the M. A. Hanna Co., containing 57.9 wt. % iron. In the main investigation a fresh representative sample of the carefully crushed, ground, screened and air-classified (40-200 U. S. standard mesh) was used for each run.

b. *Copper-Oxide-on-Silica Gel.* Owing to agglomeration difficulties at reaction temperature, the cupric oxide was deposited on silica gel. The silica gel employed was Davison Chemical Corp. Refrigeration Grade, 28-200 mesh. The gel was impregnated with an aqueous copper nitrate solution and then dried and roasted in air. The solid contained from 10 to 15 wt. % cupric oxide, and after each run was air-regenerated at about 500° C. and then reused.

c. *Coke.* The coke was metallurgical Koppers-type coke from the ovens of the Providence Coke Co. A 40-60 U. S. standard mesh-size fraction was used in the iron oxide runs and 100-140 mesh-size fraction in the copper oxide runs. These were the mesh sizes found to mix satisfactorily with the oxides. Proximate and ultimate analyses (per cent by weight) are shown in Table A.

Equilibrium Results

Equilibrium data for the reaction:

$$3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2 \quad (3)$$

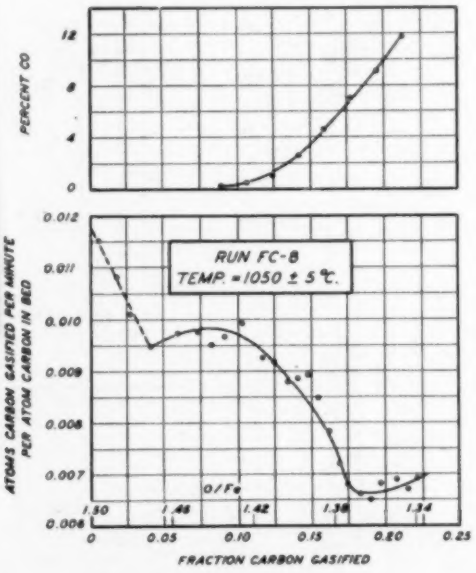

Fig. 3.

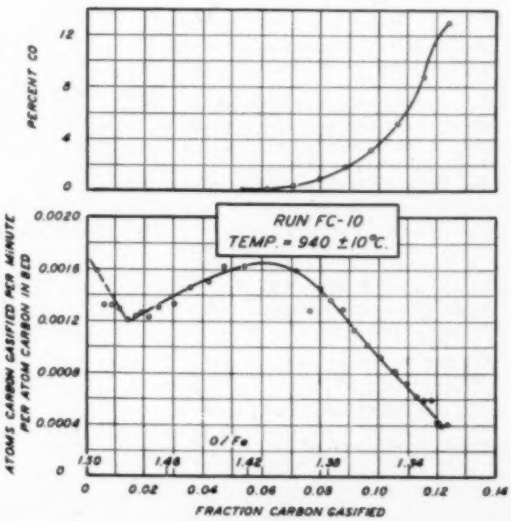

Fig. 4.

were obtained by recirculating the gas mixture through the bed of fluidized iron oxides a number of times, after which a known volume of the gas was analyzed by first passing it through caustic and ascarite in the continuous analyzer, then analyzing the tail gas for carbon monoxide by the precision Orsat technique. The results are given in Table 2. These values agree closely with the equation for the free energy change, for the reaction $2Fe_3O_4 + CO_2 \rightarrow 3Fe_2O_3 + CO$,* derived using the third law of thermodynamics and the collected data of Thompson (*18*). This equation is

$$\Delta F^\circ = 8.460 + 18.12T \ ln\ T - 5.51 \times 10^{-4}T^2 + 544.0T^{-\frac{1}{2}} - 3.44 \times 10^6 T^{-3} - 129.6T \qquad (4)$$

However, these values disagree with those quoted by Ralston (*15*) and by Marek et al. (*12*) by a factor of 1000. The reasons for this large discrepancy are not apparent.

Equilibrium data for the reaction $4CuO \rightarrow 2Cu_2O + O_2$ were obtained by slowly withdrawing approximately a 5-l. sample of circulating gas through the continuous analyzer over a period of an hour for each of the copper oxide runs before the coke was added, meanwhile maintaining the reactor pressure constant by the introduction of carbon dioxide downstream of the outlet. The caustic-insoluble tail gases were collected and analyzed as above.

Results of these determinations are shown in Table 3 and are plotted in Figure 9 along with the results of earlier investigators. It is seen that the results of this investigation lie approximately 20% higher at each temperature than the average of the earlier work. It is evident either that the cupric oxide deposited thinly on the silica gel gives a higher oxygen partial pressure than the normal form, or that solid solution effects are present when only a small fraction of cuprous oxide is present, as was the case here.

Interpretation of Data

Mechanisms. Considering first the possible mechanisms for the gasification of the carbon and the reduction of the oxides: there is every indication during both the *FC* (iron ore-coke) and *CC* (copper oxide-on-silica gel-coke) runs that no significant amount of direct solid-solid interaction takes place; rather, there is every indication that the mechanism of reaction of the coke with the oxide is by consecutive gas-solid reactions. Two possible gas-solid mechanisms exist for these oxygen-carrier reactions. The first consists of the simultaneous reactions:

gasification of carbon by CO_2,

$$C + CO_2 \rightarrow 2CO, \qquad (5)$$

and reduction of the oxide by the CO formed,

$$CO + MeO \rightarrow CO_2 + Me\dagger \qquad (6)$$

The other mechanism is thermal decomposition of the oxide, $MeO \rightarrow Me + \frac{1}{2}O_2$, producing oxygen, followed by reaction of the oxygen with the carbon, $C + O_2 \rightarrow CO_2$. Notice that since the gas phase initially is essentially pure carbon dioxide, and a large carbon dioxide concentration always remains, the first mechanism will always be taking place.

The conditions under which the direct oxidation process cannot make a significant contribution to the over-all reaction rate can be estimated from a consideration of the maximum mass-transfer rates between the gas and solid phases. From existing data (*8*), the gas phase mass-transfer coefficient to the carbon is equivalent to a reaction rate, R_c, for 120 U. S. standard mesh-size (0.125 mm. D) carbon particles, of the order of magnitude of 100 gram-atoms of carbon gasified per gram-atom of carbon in the bed, per minute, for a one atmosphere partial pressure difference of oxygen. Now the maximum contribution of the

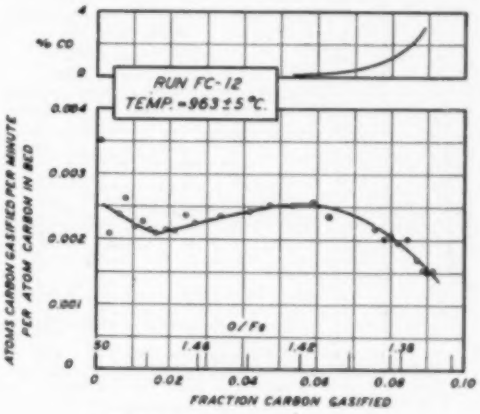

Fig. 5.

TABLE 1.

A. Run CC-6

Time min.	Average Temp. °C.	CO_2 %	$O_2 + CO$ %	N_o* milli-g. moles	N_c* milli-g. moles	$R_c \times 10^{6}$*	C Gasified milli-g. moles
0.0	957 ± 1	0.0	0.0	1151	1039	0.0	0.0
4.0	957 ± 1	99.0	0.133	898	914	8.65	126
8.0	954 ± 2	99.0	0.150	853	892	5.14	147
18.5	956 ± 0	98.3	0.811	776	854	3.80	162
21.5	955 ± 2	99.0	0.101	752	842	5.19	193
30.0	959 ± 2	99.0	0.122	685	809	4.84	224
39.0	953 ± 1	99.0	0.169	610	773	4.43	259
54.5	961 ± 1	99.0	0.130	515	726	3.51	302
70.17	960 ± 1	96.7	0.479	434	688	2.29	336
82.8	959 ± 1	99.0	1.18	387	664	2.19	358
93.17	953 ± 0	97.2	2.01	349	645	2.19	374
113.8	956 ± 0	96.4	2.86	300	621	1.57	393

Average reactor pressure: 1.095 atm.
Superficial velocity: 0.775 ft./sec.

* N_o = milligram moles of oxygen in copper oxide in bed.
N_c = milligram atoms of carbon in bed.
R_c = gram atoms carbon gasified per gram atom carbon in bed per minute.

B. Iron Oxide Runs

Run *FC*-12

Time min.	T °C.	CO%	$R_c \times 10^{6}$*	C Gasified g. moles
0	974 ± 1	0.0	0.0	.00
2	964 ± 4	.....	3.51 ± .09	.01
6	966 ± 1	0.6 ± 0.3	2.09 ± .04	.04
10	966 ± 1	1.1 ± .1	2.38 ± .09	.06
19	965 ± 1	0.9 ± .1	2.19 ± .05	.12
25	965 ± 1	1.0 ± .1	2.14 ± .04	.16
35	965 ± 1	1.0 ± .1	2.16 ± .11	.21
45	965 ± 1	0.9 ± .2†	2.37 ± .22†	.27
60	964 ± 1	1.0 ± .1	2.26 ± .10	.35
80	965 ± 1	0.9 ± .3†	2.42 ± .02	.47
100	966 ± 1	0.9 ± .3†	2.52 ± .04	.60
120	963 ± 1	.....†	2.35 ± .05	.71
140	960 ± 1	1.1 ± .1	2.25 ± .03	.81
150	959 ± 2	1.4 ± .1	2.01 ± .05	.88
160	960 ± 1	1.7 ± .1	1.96 ± .05	.92
180	963 ± 3	2.8 ± .1	1.53 ± .05	1.00
190	964 ± 2	4.9 ± .1	1.55 ± .10	1.03

† Data believed unreliable due to faulty operation of analyzers or counters.
Charge: 1500 g. iron ore (6.60% moisture)
3.00 g-atoms carbon (as coke)
Ore sintered 6.8 hr. before run.
Reactor pressure 935 ± 5 mm.
Superficial gas velocity 1.01 ± .06 ft./sec.

* The computation of Thompson has a numerical error in it and should read as above. His equation for $2Fe_3O_4 + \frac{1}{2}O_2 = 3Fe_2O_3$ should read $\Delta F^\circ = -56.770 + 12.82T \ ln\ T - 5.15 \times 10^{-4}T^2 + 85.67T^{\frac{1}{2}} - 3.44 \times 10^6 T^{-3} - 60.37$.

† MeO refers to any metal oxide, and Me to the next lower oxide, or the metal, itself.

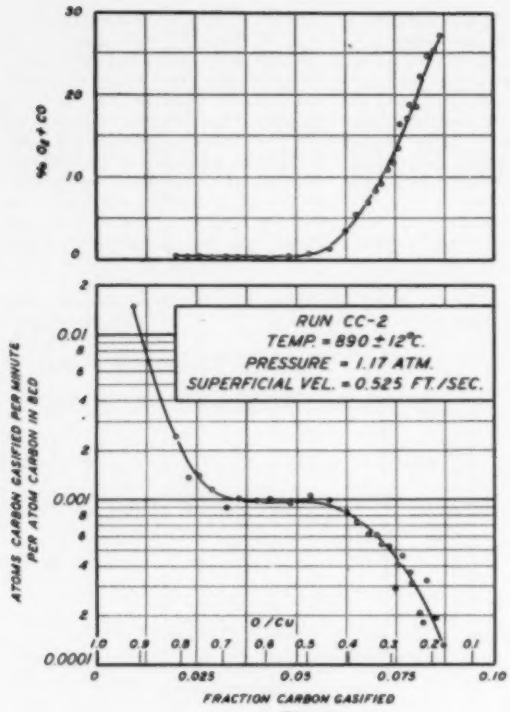
% O_2 + CO
RUN CC-2
TEMP. = 890 ± 12°C.
PRESSURE = 1.17 ATM.
SUPERFICIAL VEL. = 0.525 FT./SEC.
ATOMS CARBON GASIFIED PER MINUTE PER ATOM CARBON IN BED
O/Cu
FRACTION CARBON GASIFIED

Fig. 6.

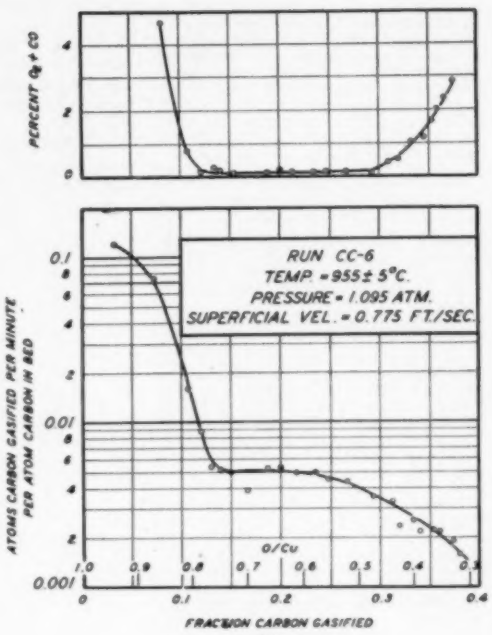
PERCENT O_2 + CO
RUN CC-6
TEMP. = 955 ± 5°C.
PRESSURE = 1.095 ATM.
SUPERFICIAL VEL. = 0.775 FT./SEC.
ATOMS CARBON GASIFIED PER MINUTE PER ATOM CARBON IN BED
O/Cu
FRACTION CARBON GASIFIED

Fig. 7.

oxygen mechanism to the gasification of the carbon will obtain when the main gas oxygen partial pressure is its equilibrium value over the oxide and the carbon surface value is zero. From the values of the equilibrium partial pressure, p_o^*, presented for the experimental equilibrium data, it can be seen that the maximum contribution for the cupric oxide step might be a value of R_o of the order of 1 (p_o^* about 10^{-2}) but with cuprous oxide and ferric oxide the value of R_o would be of the order of 10^{-6} (p_o^* about 10^{-8} atm.). When these values are compared with the experimental results given in Figures 3-8 it is noted that the contribution of direct oxidation for cuprous oxide and ferric oxide is inconsequential, but that in the case of cupric oxide it could be very large.

FC Series. When the data for the FC series are considered, (Fig. 3-5), it is seen that nearly pure carbon dioxide was obtained until the O/Fe ratio was approximately 1.40 (ratio for Fe_2O_3 = 1.5, for Fe_3O_4 = 1.33). During this period (after the initial few minutes when volatile combustible matter was given off the coke), the unit carbon gasification rate showed a slight but steady rise. Since the mechanism is restricted to the carbon monoxide and carbon dioxide reactions, and since the reacting gas was substantially pure carbon dioxide, the rise in the unit rate, at constant temperature and pressure, must be attributed to a change in the reactivity of the carbon with fractional carbon gasified. If this assumption is correct then the reaction rate should be a function of the fraction carbon gasified and essentially independent of the other factors. Data are plotted in Figure 10 and, except for the early part of the run when the volatile combustible matter is giving a higher initial rate, the results for a given temperature correlate well, and the lines for the different temperatures are essentially parallel, indicating that the percentage effect of the fractional carbon gasified on the reaction rate is almost independent of temperature. In order to compare the results for different runs all were corrected to the rate for 6% gasified by using the data of Figure 10. The reaction rate at 6% gasified as a function of the temperature is shown in Figure 11.

TABLE 2.

Run	Sample Volume, ml.	CO Collected, ml.	Equilibrium Constant $= P_1/P_2$	T° C.
FD-1	2,220	1.67	7.5×10^{-4}	834
F-1	20,840	14.3	6.9×10^{-4}	818
F-3	8,210	4.0	4.9×10^{-4}	654

TABLE 3.—PRE-RUN GAS ANALYSIS

Run No.	Avg. Reactor Temp. ° C.	Avg. Reactor Pressure Atm.	Mole Fraction of Oxygen × 100	Partial Pressure of Oxygen (atm.) × 10^3
CC-1	896 ± 2	1.115	1.71	19.1
CC-2	895 ± 3	1.147	1.51	17.2
CC-3	899 ± 4	1.107	1.85	20.5
CC-4	899 ± 4	1.105	1.85	20.4
CC-5	898 ± 3	1.114	1.83	20.4
CC-6	948 ± 3	1.110	4.95	54.9
CC-7	949 ± 1	1.091	5.46	59.5
CC-8	852 ± 4	1.098	0.584	6.42
CC-9	847 ± 3	1.083	0.520	5.63
CC-10	906 ± 4	1.097	1.71	18.8
CC-11	853 ± 1	1.096	0.553	6.06
CC-12	806 ± 2	1.095	0.133	1.46
CC-13	900 ± 2	1.091	1.82	19.9

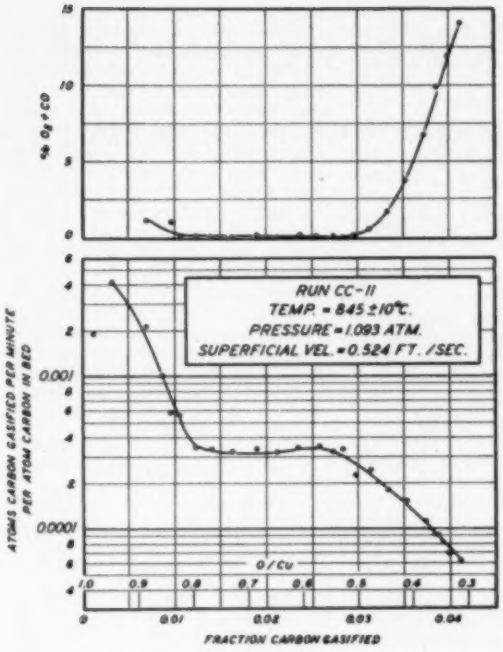
% O2 + CO
RUN CC-II
TEMP. = 845 ± 10°C.
PRESSURE = 1.093 ATM.
SUPERFICIAL VEL. = 0.524 FT./SEC.
ATOMS CARBON GASIFIED PER MINUTE PER ATOM CARBON IN BED
O/Cu
FRACTION CARBON GASIFIED

Fig. 8.

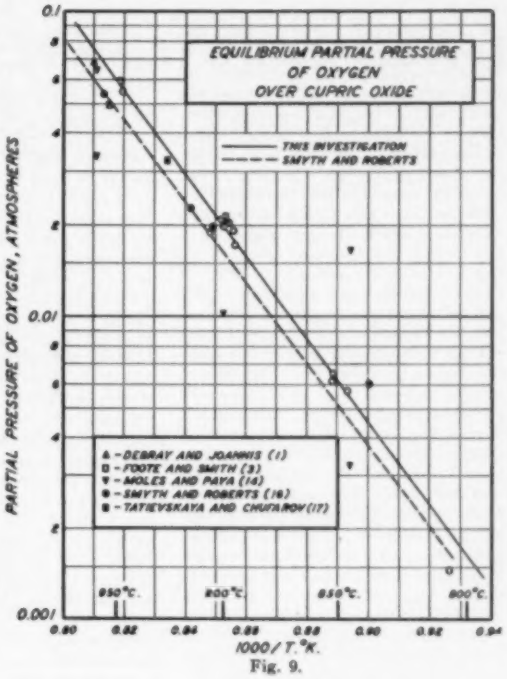

Fig. 9.

The extreme limits of the carbon monoxide concentration must be greater than the low value corresponding to equilibrium with the oxide phases and less than the high concentration corresponding to equilibrium with the carbon by the reaction $C + CO_2 \rightarrow 2CO$. Furthermore, the faster the oxide reduction rate is relative to the carbon-carbon dioxide reaction at equivalent reactant conditions, the lower the carbon monoxide concentration will be pulled by the oxide in order to maintain the rates at the relative values dictated by the steady-state system material balances. Since nearly pure carbon dioxide is produced, the $C + CO_2 \rightarrow 2CO$ reaction must be rate-controlling. The fact that the $C + CO_2 \rightarrow 2CO$ reaction is strongly retarded by the presence of small concentrations of carbon monoxide (*4, 5, 19*) supports the conclusion based on exit gas analyses, that the carbon monoxide concentration is negligible during

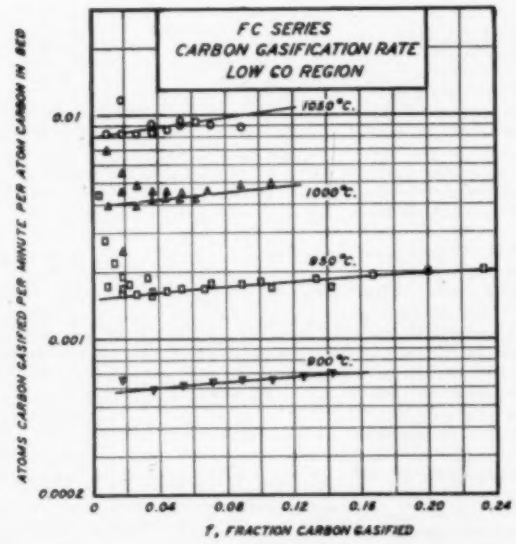

Fig. 10.

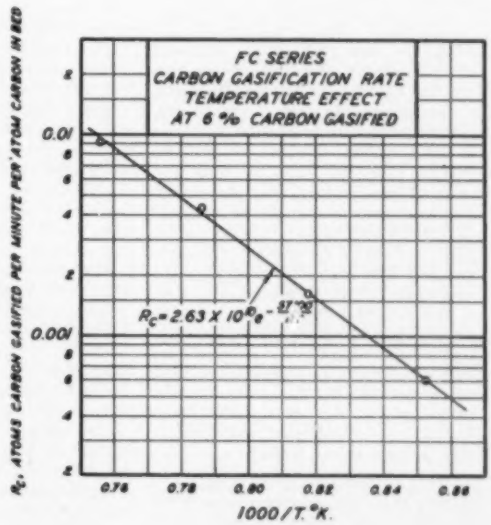
FC SERIES
CARBON GASIFICATION RATE
TEMPERATURE EFFECT
AT 6 % CARBON GASIFIED
$R_C = 2.63 \times 10^6 e^{-\frac{87,700}{RT}}$
R_C, ATOMS CARBON GASIFIED PER MINUTE PER ATOM CARBON IN BED
1000/T. °K.

Fig. 11.

the first part of a run because the carbon gasification rate is independent of carbon to oxide ratio, variations of which would be expected to change the steady-state carbon monoxide concentration.

The carbon gasification rates during the period of rapidly changing carbon monoxide concentration do not correlate with the Langmuir-type of reaction rate expression which has been found (*4, 5, 19*) to hold well for point values of the $C + CO_2 \rightarrow 2CO$ reaction rate. It is believed that the deviations from this expression are mainly due to the carbon monoxide concentration in the bed being greater than the measured carbon monoxide concentrations. That this effect is present to a significant extent when the gas phase rising through a fluidized bed is changing in concentration because of chemical reaction with the solid is well known (*6*); and it is explained by the fact that, rather than rising in uniform concentration throughout a fluidized bed, a portion of the gas rises rapidly in the form of bubbles (*9, 13*), which have only limited contact with the dense phase, thus producing mass-transfer gradients. It was not possible to observe the character of the fluidization in the metal apparatus but the pressure drop indicated that the solid was being supported by the gas. The experimental data available on the extent of the gas by-passing are not sufficient to indicate whether the problem will be more serious in a larger unit.

A few runs were made with a Disco semicoke which is chemically more reactive than the coke employed, and rates of carbon dioxide production two to ten times those given in Figures 3-5 were obtained.

CC Series. With cupric oxide and coke, the data (Figs. 6-8, inclusive) show a relatively rapid initial surge of gas for the first 30-40% of the cupric oxide reduced. Thereafter, the rate declined rapidly and leveled off to nearly constant values until nearly all the cupric oxide was used up ($O/Cu = 0.5$). These "plateau" rates were up to twice as great as would be expected (*19*) from the $C + CO_2 \rightarrow 2CO$ reaction alone, and were a function of the carbon-to-oxide ratio. Again, substantially pure carbon dioxide was produced.

The fact that in the plateau period the carbon gasification rate was a function of the carbon-to-oxide ratio even with the carbon monoxide concentration negligible confirms the presence of an oxygen contribution during this period. It can be concluded from these facts, in view of the previous deductions:

1. The contribution of the oxygen mechanism to the over-all rate is large during this initial surge period for cupric oxide deposited on silica gel.

2. Since the concentrations in the gas phase of both oxygen and carbon monoxide were low, the rate-controlling reactions were

$$C + CO_2 \rightarrow 2CO \quad (7)$$

and

$$4CuO \rightarrow Cu_2O + O_2 \quad (8)$$

Below a value of O/Cu of 0.5, Cu_2O was being reduced by the carbon monoxide and carbon dioxide reactions. Data show that at first the cuprous oxide reduction rate is such that it can maintain the carbon monoxide concentration low. In other words, again the $C + CO_2 \rightarrow 2CO$ reaction is rate-controlling. However, at an O/Cu ratio of about 0.4, before much of the Cu_2O is reduced, the carbon monoxide concentration begins to build up and the rates of reaction fall off as the cuprous oxide reduction tends to become rate-controlling. It would appear from this increase in resistance to reaction long before the cuprous oxide becomes small in amount that the cuprous oxide reduction reaction is limited by a skin of copper formed on the cuprous oxide surface. Furthermore, in both the cupric oxide and cuprous oxide reduction stages, the rates become smaller than might be expected from a resistance proportional to the relative thickness of the reduced layer present, when 40-50% of the oxide is consumed. It is believed that in both cases this is due to the fact that only 40-50% of the cupric oxide deposited on the silica gel is readily accessible. The rest of the oxide may have been in silica gel pores which were not so readily available to the gas. Because of the low rates involved, the runs were not continued beyond the point where 40-50% of the cuprous oxide had been reduced.

Engineering Significance

As previously mentioned, it was necessary for fluidization purposes that the cupric oxide be supported on a carrier. The combination with silica gel proved to have poor durability, i.e., some of the copper gradually sloughed off, gathering in clumps at the bottom of the reactor or blowing overhead as fines. It is therefore concluded that the copper oxide-on-silica gel used in this investigation is not a suitable oxygen carrier for industrial operation. A more suitable support for the copper oxide might be found. Experimental results indicate that during the cupric oxide stage the rates are significantly higher than with the iron oxide and copper oxide would appear desirable for this reason. In any case, the contamination of the oxide with ash would offer more difficulties with copper than with iron because of the high recovery necessary with the copper.

In the case of the hematitic iron ore, rough calculations have shown that the reduction rates with the coke employed in this investigation with a reactor 2 ft. in diameter and 20 ft. high would produce from 10 to 15 tons of carbon dioxide/day. Production rates several times as great could be obtained by using a more active form of carbon. Thus, since ferric oxide appears satisfactory from the points of view of both rates of reaction and as a practical "oxygen carrier," this process appears worthy of further study. The problems of carbon and ash separation from the recirculating hematite need still to be worked out.

In the work reported here, a fresh sample of iron oxide was used in each run. In subsequent work the iron oxide has been carried through a limited number of cycles of reaction and regeneration without any apparent changes in reactivity or particle size.

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(*Presented at Boston Meeting, Swampscott, Mass.*)

ABSORPTION ON A SEMI-WORKS SCALE

Absorption of Sulfur Dioxide in Water in a Packed Tower

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The influence of tower height and of chemical reaction between the solute and solvent have been investigated for the absorption of sulfur dioxide in water in a semi-works scale packed tower over the commercial range of operating conditions. The tower was packed with 1-in. Raschig rings.

Because of the close approach to equilibrium in many of the runs, the literature dealing with equilibrium solubility of sulfur dioxide in water has been studied, smoothed, and correlated to yield recommended equations representing the equilibrium over a range of 0 to 50° C. and of 0 to 800 mm. Hg. of sulfur dioxide.

Experimental mass-transfer data have been expressed in terms of heights of transfer units. These are found to agree satisfactorily with similar sulfur dioxide absorption data secured by Whitney and Vivian from a tower one tenth as tall in which end effects were eliminated.

The experimental heights of transfer units range from approximately those predicted by the usual correlations on up to twice these values. Much better agreement is obtained when the results are expressed as pseudoheights of transfer units corresponding to the pseudoequilibrium and operating lines suggested by Vivian and Whitney.

THE general procedures for the design of packed towers are based on the two-film theory of Whitman as elaborated by a number of authors (*4, 16, 29*). Although these methods are widely useful, some uncertainties still exist with respect to treatment of certain factors.

One of these uncertainties is the influence of the scale and geometry of the absorption equipment on the values of mass-transfer coefficients. This concerns the degree of reliability with which such coefficients secured in small-scale apparatus may be used directly, after proper account for end effects, in the design of large-scale equipment. Van Krevelen and Hoftijzer (*25*), for example, after analyzing a large mass of data from the literature suggested that the liquid film mass-transfer coefficient, k_La, varies inversely as the cube root of the tower height for a given packing material. The true situation has been complicated by end effects which exert considerable influence on the results from shorter towers.

Another uncertainty in systems where the solubility depends in part upon a chemical reaction between the solute and the solvent is the influence of the rate of reaction. The general treatment for this case is complex (*16, 26*). However, a simplified approach for one limiting case has been advanced recently by Whitney and Vivian and has been applied with considerable success to the absorption of chlorine in water (*27*) and to the absorption of sulfur dioxide in water (*30*).

The present investigation was undertaken because of the above-mentioned uncertainties as to the proper design of large-scale sulfur dioxide absorbers and because of the importance of adequate design to conserve sulfur dioxide and to avoid atmospheric pollution. A number of reports have appeared in the literature (*1, 5, 8, 30*) setting forth mass-transfer coefficients for absorption of sulfur dioxide in water using various types of packing. However, nearly all these investigations have been conducted with relatively short towers containing 6 in. to 6 ft. of packing.

One of the objectives of the present investigation was to obtain mass-transfer data in a semi-works scale packed tower for essentially complete absorption of sulfur dioxide in water to give liquors of high strength, and thus to attempt to eliminate most scale-up uncertainties in the design of commercial absorbers.

Another objective has been the comparison of the results obtained with those from shorter towers and with those predicted by the usual correlations to help clarify the proper prediction and scale-up of mass-transfer data. Actual comparisons reported here are limited to the extensive experimental data of Whitney and Vivian (*30*) which were obtained in an 8-in. diameter tower packed with 2 ft. of 1-in. ceramic rings under conditions such that end effects were eliminated.

Equipment and Procedure

In essence, the present experiments comprised the flowing of a mixture of sulfur dioxide and air through a packed absorption tower countercurrent to water, and the measuring of the extent of absorption of the sulfur dioxide. The apparatus is shown schematically in Figure 1.

Absorption Tower. The absorption tower was 24 ft. tall, of 12 in. I.D., and was packed to a height of 19.45 ft. with 1-in. ceramic Raschig rings dumped wet. The tower was made of No. 16 gage stainless steel with a perforated No. 10 gage stainless steel plate 30 in. from the bottom serving as a packing support. A gas space of 18 in. was provided below the packing at the base of the column, and another of 25½ in. existed at the top of the column. The gas entered through a 4-in. opening whose center line was 12 in. below the packing support. A 10-in. water seal was maintained at the base of the column.

Due to possible adverse effects of poor liquor distribution upon the final results, precautions were taken during construction to keep the absorption tower exactly vertical and to attain good initial liquor distribution at the top of the tower and thus to secure as nearly as possible a uniform distribution of liquor in the tower. As pointed out by Baker, Chilton and Vernon (*2*), if the liquor is well distributed at the top of the packing, it will maintain this distribution throughout the remainder of the column if the diameter of the packing is not too large in proportion to the column diameter. The water fed to the tower was admitted 2½ in. above the top of the packing through a spray-head-type distributor made from a section of 4-in. antimonial-lead pipe. The spray-head contained 61 $\frac{5}{64}$-in. holes drilled at such spacing and angle as to give distribution as uniformly as possible over the surface of the packing.

The gas fed to the tower consisted of a mixture of sulfur dioxide and air contain-

† Present address: Puget Sound Pulp and Timber Co., Bellingham, Wash.
‡ Present address: G. D. Jenssen Co., Inc., Seattle, Wash.

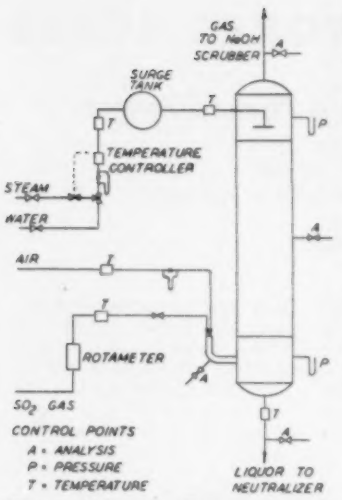

Fig. 1. Schematic diagram of semi-works scale sulfur dioxide absorption tower.

ing about the same proportion of sulfur dioxide as is normally found in sulfur burner gas. Air was supplied at 30 lb./sq.in. gage from a blower. Liquid sulfur dioxide contained in a battery of six 150-lb. cylinders, situated in a steam-heated water bath, was vaporized at constant pressure, flowed through a rotameter, and then mixed with air. The gas mixture was passed through a 3-ft. length of 4-in. lead pipe and finally through a funnel provided with vanes to insure complete mixing before admission to the tower.

Gas leaving the top of the column was vented through a 4-in. diameter lead pipe to the top of another wooden tower in which it was scrubbed with a 2% sodium hydroxide solution to remove residual sulfur dioxide before being discharged into a stack. The sulfurous acid solution flowed from the absorption tower through a 2-in. diameter pipe to a tank in which it was neutralized with the excess 2% sodium hydroxide solution leaving the alkaline scrubbing tower and then was discharged to the sewer.

Control Measurements. Temperatures of the entering air and sulfur dioxide were measured by use of appropriately placed resistance thermometer bulbs connected to a three-point Model *S* Leeds and Northrup Micromax recorder. The third bulb in the outlet liquor corroded away after the first few runs. It was replaced by a thermowell and mercury thermometer for runs 24 to 30. The temperature of influent water was measured by a similar single-point recorder. All connections to the recorders were checked against a standard resistance coil supplied by the Leeds and Northrup Co., and the over-all assembly was found to record temperature accurately to within 0.1° C. compared with an accurate mercury thermometer.

Static pressures in the tower at top and bottom were measured by use of water-filled *U*-tube manometers. The sulfur dioxide pressure gage was calibrated against a dead-weight tester.

The flow rate of influent sulfur dioxide was manually controlled and was observed by means of a Schutte and Koerting rotameter. Air and liquor flow rates were measured by sharp-edged orifices suitably connected with 30-in. mercury manometers, and these meters were calibrated several times during the course of the investigation. The influent water was heated by a steam-jet heater, and its temperature was controlled by means of a Scientific No. 3500 nonindicating temperature controller.

Analyses. Analyses for sulfur dioxide were made on the gas entering and leaving the tower and also in runs 24 to 30 on a gas sample drawn from the tower at a distance of 11.8 ft. up from the bottom of the packing. The method of Reich (*14, 22*) involving bubbling the gas sample through a diffuser disk and up through a known volume of standardized iodine solution until the starch-iodine end point was reached was employed. Concentration of sulfur dioxide in the liquor leaving the base of the tower was also determined by iodine titration. To prevent flashing of sulfur dioxide from the sample during pipetting, an aspirator bulb was used to apply pressure in the flask holding the liquor sample and thereby to force the sample up into the pipette.

Procedure. (a) Flow rates of air and water were adjusted approximately to the desired values; (b) temperature equilibration was approximated; (c) the feeding of sulfur dioxide was initiated; (d) final adjustments of the temperature, flow rates, and entering gas composition were made; and (e) analyses of gas and liquor streams were made at approximately 5-min. intervals until equilibrium had been established. The following data were taken: sulfur dioxide rotameter reading, air orifice reading, water orifice reading, temperature of entering air, temperature of entering water, temperature of exit water, temperature of entering sulfur dioxide, temperature of bath for vaporizing sulfur dioxide, and the static pressure at the top and bottom of absorption tower.

Scope of Experiments. In the 30 runs made 16 were excluded wholly and four partly because there occurred either too extensive absorption from the gas or too extensive saturation of the liquor to permit these effluent streams to be analyzed adequately. In eight of the runs the sulfur dioxide in the outlet gas was so dilute that it could not be determined with the apparatus and time available. Five more runs were excluded because the outlet liquor concentration was greater than 96.4% of what was calculated to be the saturation value. Such results tend to be highly unreliable because the driving force for mass transfer at the base of the tower is so small that calculations based on it are greatly affected by even minor errors in liquor temperature measurement, gas or liquor analyses, or in the solubility data. An exception was made in the case of run 24 with 97.2% saturation because the data were unusually consistent. However, three more runs were excluded because their data were too erratic.

The principal data for the remaining 14 runs are given in Table 2. In four of these only the top or bottom sections of packing are considered for the same reasons as just given. In the accepted experiments, the outlet liquor temperatures ranged from 19° to 32° C., the liquor rates from 4930 to 7490 lb./(hr.)(sq.ft.), the outlet gas rates from 148 to 335 lb./(hr.)(sq.ft.), and the inlet sulfur dioxide concentrations from 5.4 to 18.0 moles/100 moles of dry air. The sulfur dioxide content of the gas stream was reduced from 8- to 2400-fold while producing outlet liquor concentrations ranging from 60 to 97% of saturation.

Equilibrium Data

Equilibrium was approached so closely in many of the runs that phase-equilibrium data useful for the calculations had to be of a good order of accuracy. The degree of departure from equilibrium at the base of the tower in the several runs is indicated in Table 2 under the heading "per cent saturation of liquor leaving the section." A comparison among the two sets of equilibrium data listed in Perry (*13*), showed discrepancies ranging from 1 to 15% in the equilibrium pressures over the range of temperatures and concentrations encountered in this investigation. That neither of these sets of data is entirely reliable is indicated by the fact that neither gives a smooth plot of the logarithm of pressure vs. reciprocal temperature at constant liquor composition. Accordingly, a critical review of the literature on the solubility of sulfur dioxide in water was undertaken.

Correlation of the solubility data was accomplished by a method similar to that used by Johnstone and Leppla (*10*). Johnstone and Leppla postulated that the solubility relations for this system may be expressed by the following three equations:

$$c_t = c_u + c_i \qquad (1)$$

where c is the concentration of SO_2 in gram moles/1000 grams of water and the subscripts indicate total, nonionized and ionized, respectively:

$$c_u = Hp^* \qquad (2)$$

TABLE 1.—RECOMMENDED DATA FOR EQUILIBRIUM BETWEEN SULFUR DIOXIDE IN GAS PHASE AND IN WATER SOLUTION

(0 to 50° C.; 0 to 800 mm. Hg. Partial Pressure of SO_2)

$c_t = c_u + c_i$, total SO_2 concentration, g.moles/1000 g. H_2O
$c_u = Hp^*$, nonionized SO_2 concentration, g.moles/1000 g. H_2O
p^* = partial pressure of SO_2 at equilibrium, mm. Hg.
H = Henry's law constant, g.moles SO_2/(1000 g. H_2O)(mm. Hg.)
$c_i = \sqrt{Kc_u}/\gamma_i$, ionized SO_2 concentration, g.moles/1000 g. H_2O
γ_i = effective ionic activity coefficient
K = ionization constant for first hydrogen ion

$$\log_{10} H = \frac{1368.43}{273.1 + t} - 7.37566$$

$$\log_{10} K = \frac{843.33}{273.1 + t} - 4.71507$$

t = temperature in ° C.

Recommended Coordinates for Plot of γ_i vs. $\gamma_i c_i = \sqrt{Kc_u}$

γ_i	1.000	0.948	0.904	0.884	0.863	0.852	0.837	0.827	0.820	0.820
$\gamma_i c_i$	0.000	0.003	0.007	0.010	0.015	0.020	0.030	0.0400	0.050	0.100

where p^* is the equilibrium partial pressure of sulfur dioxide and H is the Henry's law constant; and

$$c_i = \frac{\sqrt{Kc_a}}{\gamma_i} \qquad (3)$$

where γ_i is the mean ionic activity coefficient for hydrogen ions and bisulfite ions in the solution and where K is the ionization constant for the reaction:

$$SO_2 + H_2O \rightleftharpoons H^+ + HSO_3^- \qquad (4)$$

By analyzing their own data and those of Morgan and Maass (*12*) and of Campbell and Maass (*3*) on the solubility and electrical conductivity of sulfur dioxide solutions, and by further assuming that the mean ionic activity coefficient for hydrogen and bisulfite ions would be the same as for hydrogen and chloride ions, Johnstone and Leppla calculated values of H and of K for a number of temperatures over the range of 0° C. to 50° C. They showed that these values were essentially independent of concentration over the range of partial pressures studied, from about 0.0003 to 1.07 atm. SO_2 partial pressure. They also showed that logarithm H vs. reciprocal temperature and that logarithm K vs. reciprocal temperature plots were essentially straight lines with slopes corresponding to a heat of solution of nonionized sulfur dioxide in water of 6260 cal./g. mole and to a heat of ionization of 3860 cal./g. mole ionized.

Present calculations required smoothed values of H and K for the evaluation of effective ionic activity coefficients from all the available solubility data. Values of H and K reported by Johnstone and Leppla were used to establish the equations for H and K shown in Table 1.

The effective mean ionic activity coefficients were next calculated for nearly all the data (*3, 5, 7, 8, 10, 12, 15, 19-21, 28*) reported in the literature relative to the solubility of sulfur dioxide in water in the range of 0 to 50° C. and 0.0003 to 1.07 atm. sulfur dioxide partial pressure. For each point, the total solubility was converted to the units of c_i, c_a was calculated from H and the partial pressure, c_i was found by difference, and finally γ_i was calculated from Equation (3).

It should be noted that any errors in the values of H or K affect the value of γ_i found, so that the latter should be considered the effective ionic activity coefficient for use with the above values of H and K. Values of H correspond to nonionic activity coefficients of the order of 10 to 12. With such large positive deviations from Raoult's law as these it would be expected that the nonionic activity coefficient, and hence the values of H, would change appreciably over the range of concentrations

TABLE 2.—ABSORPTION OF SULFUR DIOXIDE IN WATER

(Experimental Data and Calculated Results)

Run Number	5	7	9	11	12	14	17	23	24	26	27	27	27	28	29	30
Section Tested (O—overall, T—top, B—bottom)	O	O	O	O	O	O	O	O	O	B	O	T	B	B	T	B
Data																
L, lb. H_2O/(hr.)(sq.ft.)	6510	4960	4980	4980	4930	4930	4930	6450	4930	7490	4930	....	....	6450	6450	7480
Pressure at top of tower, mm. Hg.	764	764	756	756	759	759	756	761	763	769	763	....	....	762	....	....
Pressure drop across packing, H_2O, in.	1.5	1.3	0.6	....	....	....	0.9	....	1.9	1.2	1.3	....	....	1.3	1.3	1.9
Temperatures, ° C.																
H_2O to tower	18.0	38	23	29	17	22	22.5	25	31	31	25	....	....	20	25	....
Air to tower	30.0	26	30	30	30	30	30	34	36.5	37	37	....	....	37	36.5	37
H_2O to tower	19	17.6	17.8	16.9	18	18	31.55	25.1	17.1	24.3	24.3	....	....	24.3	29.9	29.8
Liquor from tower		19.9	19.5	19.25	19.5	19.7	20.6	26.4	19.25	26.07	25.86	....	....	25.60	30.70	30.47
SO_2 concentrations																
Inlet gas, moles/100 moles dry air	5.897	17.72	16.88	16.99	16.58	17.18	6.007	16.80	18.29	16.29	18.74	11.07	18.74	18.09	8.59	17.41
Outlet gas, moles/100 moles dry air	.0037	.0080	.0069	.0080	.113	.0154	.763	.334	.0133	.0143	.0127	2.22	11.07	.592	1.08	.940
Outlet liquor, lb./100 lb. H_2O	.614	1.734	1.122	1.572	1.493	1.292	.489	1.200	1.903	1.142	1.517	.811[1]	1.517	1.297	.551[1]	1.110
Calculated Results																
G, lb. dry air/(hr.)(sq.ft.)[2]	385	230	146	185	208	167	212	218	252	212	204	204	204	207	223	216
Temperatures, ° C.																
Liquor to section	19.00	17.60	17.50	16.90	18.00	18.60	21.56	25.10	17.08	25.96	24.24	24.24	25.16	24.40	29.76	29.68
Liquor from section	19.78	19.64	18.50	18.78	19.80	19.56	21.90	26.40	19.28	26.22	25.86	25.16	25.86	25.76	30.34	30.78
SO_2 partial pressures, mm. Hg.																
Gas to section	30.58	112.8	107.0	118.1	105.6	104.7	40.85	106.0	116.0	114.0	116.8	16.02	116.8	115.1	56.0	108.3
Gas from section	.0275	.37	.0508	.0590	.830	.114	5.49	2.45	10.43	.0934	16.02	73.6	73.6	4.37	7.80	6.83
Performance of section																
Ratio inlet to outlet gas concentrations	1450	262	2445	2375	1460	1115	78.6	505	12.9	1615	8.44	4.98	1.695	80.55	7.87	18.53
Per cent saturation of liquor leaving section	83.20	91.70	70.10	75.70	84.40	76.20	95.5	87.0	92.2	74.7	96.4			84.0	76.9	89.0
Area, A, sq. ft.	11.80	11.80	10.50	11.49	11.46	9.83	6.11	7.67	7.88	10.66	6.75	2.74	4.60	7.20	9.84	7.92
N_{OG}	5.81	5.87	5.49	5.81	5.86	4.97	7.43	6.08	8.78	5.18	7.56	2.69	5.00	5.42	4.52	6.66
Eqs. N'_{OG}	14.66	13.60	6.64	8.98	9.25	7.21	10.40	8.70	11.50	9.54	9.46	3.53	5.94	7.50	6.75	8.75
Eqs. N''_{OG}	1.93	1.51	3.10	2.12	1.44	2.25	0.83	1.27	0.89	2.06	0.89	1.02	0.78	1.33	1.11	1.19
Average L/mG	0.77	0.85	1.53	1.28	0.91	1.33	0.59	0.88	0.68	1.12	0.71	0.80	0.68	0.96	0.78	0.91
Average pseudo L/mG	0.38	0.47	1.53	1.28	0.91	1.33	0.59	0.88	0.68	1.12	0.71	0.80	0.68	0.96	0.78	0.91
H_{OG}, ft.	2.17	2.17	3.59	3.59	2.69	4.55	2.69	3.33	2.81	2.29	2.57	2.84	2.16	2.18	1.95	1.95
Pseudo H'_{OG}, ft.	1.33	1.41	1.28	1.28	2.20	1.97	2.20	2.65	1.97	1.64	2.70	2.77	2.77	1.68	1.70	1.67
H_{OL}, ft.	1.49	1.35	2.34	2.80	2.11	3.42	2.11	2.51	1.43	1.74	2.37	2.58	2.01	1.27	1.62	1.46
H_G, ft.[3]	1.49	1.19	2.08	2.08	2.27	3.00	2.86	2.86	1.53	1.93	1.92	2.08	1.79	1.27	1.62	0.98
Pseudo H'_G, ft.	0.79	0.77	1.83	1.26	1.45	1.78	1.43	1.64	1.16	0.93	1.54	1.59	1.49	0.93	1.14	0.74

[1] Calculated by an SO_2 balance.

[2] Assumes air only has come to equilibrium with outlet liquor with respect to temperature and humidity before entering the packing.

[3] Calculated from the equation of Whitney and Vivian (*28*) for conditions at top of tower.

[4] Assumes total gas stream saturated with water vapor at liquor temperature.

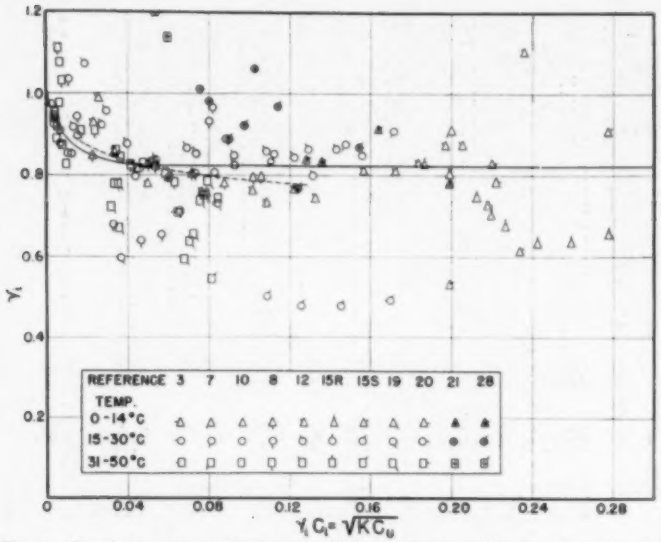

Fig. 2. Correlation of gas-solution equilibrium data for sulfur dioxide and water by use of effective ionic activity coefficients.

encountered. Furthermore, Tartar and Garretson (*23*) using electromotive force studies concluded that, at 25° C., K was nearer to 0.0170 than to the 0.0130 found by Johnstone and Leppla. Accordingly it would be expected that the effective ionic activity coefficients might not vary in the usual manner with ionic strength and temperature.

What are considered to be the most reliable and consistent values of γ_i have been plotted against $\gamma_i c_i$ in Figure 2. Before selection of the data a large number of widely scattered points were obtained, the scattering probably resulting from the fact that errors in analysis, temperature, partial pressures, and attainment of equilibrium all accumulate and are magnified in the calculated concentration of the ionized sulfur dioxide upon which γ_i depends. Individual points were excluded from the plot when concentrations or partial pressures were not stated to closer than one part in twenty (e.g., 1.4 mm. would be omitted). In addition, all points for which c_i was less than half of c_u were excluded when concentrations or partial pressures were not stated to better than one part in one hundred. Whole series of points secured in a particular investigation at constant temperature were not used if successive points in the series showed large, sudden, and erratic changes, notably much of the data of Campbell and Maass (*3*), Sims (*20*), and Conrad and Beuschlein (*5*). Certain other points were excluded by the range of values selected for plotting. The remaining points have been plotted in Figure 2.

The recommended values of γ_i for use in Equation (3) from 0 to 50° C. are indicated by the solid line in Figure 2. The broken line in the figure shows the values of γ_i used by Johnstone and Leppla at 25° C. The corresponding theoretical curves for 0° C. and for 50°C. would lie one or two per cent higher, and lower than the broken line respectively. Even after selection, the points scatter widely on both sides of the broken line making evaluation of the best average difficult and completely obscuring any trend due to temperature. At low sulfur dioxide concentrations, the recommended line drops off more rapidly than the theoretical due to great weight being given Johnstone and Leppla's extensive measurements which were designed for and confined to this region. At higher concentrations the recommended line levels out above the theoretical at 0.82. In spite of the scattering of the data it would be difficult to justify a line as much as either 0.03 above or below the line drawn. It should be noted that an error in 0.03 in γ_i at 25° C. would result in errors in predicting the total sulfur dioxide concentration of about 0.8% relative for a 2% solution and of 1.7% relative for a 0.25% solution.

Calculation Methods

Heat and Material Balances. The reliability of each run reported in Table 2 was checked by a material balance which generally agreed within 5%. The gas rate was considered to be the least accurate of the quantities measured, so the gas mass velocities reported in Table 2 were calculated by material balances.

Heat balances were used to verify the differences observed between the inlet and outlet liquor temperatures. The heat of solution to nonionized sulfur dioxide was taken as 6,260 cal./g. mole and that to ionized sulfur dioxide as 10,120 cal./g. mole (*10*). Together they accounted for temperature rises of 0.6 to 2.0° C. and usually were the major heat effects. Heat leak into or loss from the uninsulated column was ratioed up according to the average difference in temperature between the liquor and the room from one experimental determination in which cold liquor but no gas was flowing through the tower. The heat leaks and losses were equivalent to as much as 0.20° C. in several runs. An approximate correction was applied for the heat effects in cooling and humidifying the inlet mixed gas stream by calculating the net heat required to bring the inlet air only to thermal and humid equilibrium with the outlet liquor stream. An inlet air humidity of 0.008 lb./lb. dry air was assumed in all cases, and net corrections from 0.04 to 0.52° C. were obtained. The last six runs showed an average deviation of only 0.08° C. between the predicted and observed temperature rises, approximately the accuracy of reading the inlet liquor temperature recorder. Runs 5 to 22 showed deviations of the order of 0.3 to 1.2° C. These were traced to the faulty practice of taking the temperature of a small sample of outlet liquor drained from the tower as the outlet liquor temperature after the original recorder bulb had corroded away. In subsequent calculations the observed inlet water recorder temperature was taken to be correct for runs 5 to 22. In runs 24 to 30, however, the inlet water temperature was back-calculated from the summation of heat effects indicated above and the observed outlet liquor temperature which was read accurately in these runs.

TABLE 3.—SUMMARIZED COMPUTATIONS OF DRIVING FORCES FOR MASS TRANSFER IN RUN 27

Z	C_l	Y	t	$P-P_w$	p	p^*	C_l^*	$\frac{1}{p-p_i^*}$	$\frac{1}{C_l^*-C_l}$	$H_c \times 10^4$	$\frac{1}{C_u^*-C_u}$
	lb. SO_2 / lb. H_2O	Moles SO_2 / Mole Dry Air	° C.	mm.	mm.	mm.	lb. SO_2 / lb. H_2O	mm^{-1}	lb. H_2O / lb. SO_2	mm.	lb. H_2O / lb. SO_2
ft.											
19.45	0.0000	0.0222	24.24	739.8	16.02	0.00	0.00315	0.0623	317	1.0793	578
	0.00384	0.0642	24.69		44.6	20.9	0.00712	0.0421	305	1.0622	397
11.8	0.00812	0.1107	25.16		73.0	53.2	0.01072	0.0490	585	1.0446	469
	0.01153	4.1479	25.53		95.3	81.3	0.01326	0.0714	578	1.0310	693
	0.01261	0.1619	25.64		102.9	92.0	0.01416	0.0917	752	1.0270	895
	0.01409	0.1758	25.76		110.3	102.9	0.01499	0.1350	1111	1.0227	1220
0.0	0.01516	0.1874	25.86	739.6	116.8	112.0	0.01573	0.2080	1754	1.0191	2045

Experimental Number of Transfer Units. Calculations involved in obtaining the driving forces for mass transfer from this point on are illustrated for run 27 in Table 3.

For each run various liquor concentrations throughout the tower were assumed, and the corresponding liquor temperatures, t, were calculated by correcting the inlet water temperature for heats of solution and ionization and for heat leaks and losses. The latter were apportioned according to arbitrary estimates of the column lengths between the assumed liquor concentrations. No allowance was made for humidification or dehumidification heat effects within the packing. This was equivalent to assuming that the air fraction of the inlet gas was instantaneously brought to equilibrium with the outlet liquor as it entered the packing and that no further transfer of water vapor occurred in either direction within the packing. This assumption slightly reduces the driving force for mass transfer of sulfur dioxide at the base of the tower, but it is believed not to introduce any serious error in a tower of this size. In run 27 about 1.5 water vapor transfer units would have been required to raise the humidity of the inlet air only from 40% to 100% humidity, equivalent to about 85% relative humidity for the mixed gas stream. This should have been accomplished in less than 1.0 ft. of packing or about one third of a sulfur dioxide transfer unit.

The sulfur dioxide concentrations corresponding to the various liquor concentrations throughout the tower were then calculated. The mole ratios, Y, (moles sulfur dioxide/mole dry air) came directly from material balances involving the gas and liquor rates and the liquor compositions in appropriate units. The partial pressures, p, were calculated from the mole ratios and the combined partial pressures of sulfur dioxide and dry air. The latter, $P - P_w$, were found by subtracting the vapor pressure of water from the total pressure in the column. The resulting normal operating line for run 27 is plotted in Figure 3.

The equilibrium sulfur dioxide concentrations, C_t^* for equilibrium with p, and p^* for equilibrium with C_t, were interpolated to the corresponding liquor temperatures from a large plot of the isothermal equilibrium lines made at 2° C. increments. The isothermal equilibrium lines had been calculated from the relations in Table 1. The nature of the nonisothermal equilibrium lines obtained is illustrated for run 27 in Figure 3. The normal equilibrium line there shown is actually made up of two almost coincident lines, one for p vs. C_t^* and the other for p^* vs. C_t. The over-all driving forces for mass transfer, $p - p^*$ and $C_t^* - C_t$, in practice were calculated directly from the individual partial pressures and concentrations rather than from charts such as Figure 3.

It was desired also to apply Vivian and Whitney's (*27, 30*) concept of a pseudodriving force based on unreacted or unionized sulfur dioxide concentrations to the results of the present investigation. This concept is designed for the particular case of gas absorption where the solubility of the gas is due in part to a chemical reaction which proceeds slowly enough so that negligible reaction occurs in the interfacial liquid film, but fast enough to produce substantial chemical equilibrium in the bulk of the liquid beyond the film.

The pseudodriving force is the difference between C_u^* and C_u. C_u^*, the concentration of nonionized dissolved sulfur dioxide which would be in equilibrium with the gaseous sulfur dioxide at the partial pressure at which it exists in the gas stream, is equal to $H_e p$. H_e is the Henry's law constant for the liquor temperature concerned and may be found from the equation in Table 1. C_u is the actual concentration of nonionized sulfur dioxide in the bulk of the liquor. It would be difficult to determine experimentally but can be approximated by use of the assumption made by Vivian and Whitney that it is in chemical equilibrium with the reacted or ionized portion. In this case, p^*, the partial pressure which would be in physical and chemical equilibrium with C_t, is given by $C_u = H_e p^*$ since the ionized portion is nonvolatile. Accordingly, the pseudoliquid driving force, $C_u^* - C_u = H_e(p - p^*)$, and allowance need only be made for variation in H_e with the liquor temperature. The over-all gas-phase driving force remains as in the normal case. The pseudoequilibrium line, p vs. C_u^* and p^* vs. C_u, and the pseudo-operating line, p vs. C_u, have been illustrated in Figure 3 for run 27.

The numbers of transfer units based on the over-all gas driving force, $p - p^*$, on the normal over-all liquor driving force, $C_t^* - C_t$, and on the pseudoliquor driving force, $C_u^* - C_u$, were found by graphical integration of the following equations:

$$N_{OG} = \int_{p_2}^{p_1} \frac{dp}{p - p^*} \qquad (5)$$

$$N_{OL} = \int_{C_{t2}}^{C_{t1}} \frac{dC_t}{C_t^* - C_t} \qquad (6)$$

$$N'_{OL} = \int_{C_{u2}}^{C_{u1}} \frac{dC_t}{C_u^* - C_u} = \int_{C_{u2}}^{C_{u1}} \frac{dC_t}{H_e(p - p^*)} \qquad (7)$$

In Equation (5) terms correcting for variation in the mean partial pressure of inerts have been ignored since they are small compared with the total number of transfer units in the tower. In Equation (7) the amount of solute transferred under the influence of $C_u^* - C_u$ must still be measured in terms of the change in the total sulfur dioxide in the bulk of the liquor so that the numerator still contains dC_t. The graphical integrations for N_{OL} and N'_{OL} are illustrated for run 27 in Figure 4.

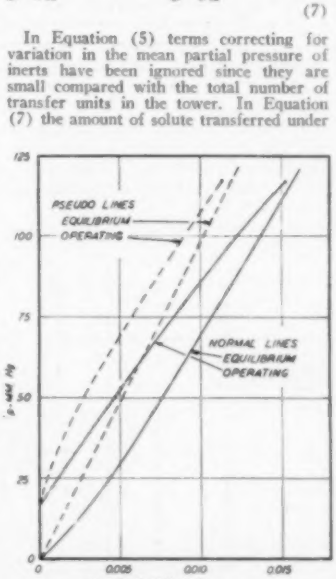

Fig. 3. Normal and pseudoequilibrium and operating lines for run 27.

Experimental Heights of Transfer Units. Results of this investigation have been correlated by the *H.T.U.* method, but they may easily be converted (*30*) to mass-transfer coefficients if desired by relations of the type:

$$H_{OL} = \frac{Z}{N_{OL}} = \frac{L}{pK_L a} \qquad (8)$$

The authors prefer use of *H.T.U.* values because of the relatively slight effect of gas and liquor rates on H_L and H_G in the approximate relation:

$$H_{OL} = H_L + \frac{L}{mG}(H_G) = \frac{L}{mG}(H_{OG}) \qquad (9)$$

H.T.U. values have been calculated based upon the actual depths of packing involved and are recorded in Table 2. No correction has been applied for end effects at either end of the tower since these effects are small compared with the length of the sections tested and are probably comparable to the corresponding end effects in commercial towers.

Since the relative slopes of the operating and equilibrium lines vary widely in each run from the top to bottom of the tower, it was difficult to select the proper average L/mG for use in Equation (9). The method adopted consisted of taking the ratios of the numbers of transfer units as follows:

$$\frac{L}{mG} = \frac{H_{OL}}{H_{OG}} = \frac{N_{OG}}{N_{OL}} \qquad (10)$$

This necessarily satisfies the H_{OL} and H_{OG} relations of Equation (9). In evaluating the effective $L/m'G$ for use with the pseudo H'_{OL} values, N_{OL} was replaced by the pseudo N'_{OL} in Equation (10).

Predicted H.T.U. For comparison with experimental results, predictions of the probable values of H_{OL} have been made by the generally accepted methods which consist of calculating H_L and H_G, and combining the two into H_{OL} by the factor L/mG as indicated in Equation (9). The only differences between the pseudo and normal cases are that the factors L/mG will be different, and that in applying the pseudo H'_{OL} to tower design the pseudo N'_{OL} must be used in place of the normal N_{OL}.

Values of H_L were predicted at $L = 5000$ for a number of temperatures according to the equation recommended by Sherwood and Holloway (*18*) for one-inch Raschig rings. This equation requires a value for the diffusivity of sulfur dioxide in water. The value used by Whitney and Vivian (*30*) at 21.1° C. was 1.66×10^{-4} sq.cm./sec. The same value, corrected for temperatures according to T/μ (*13*) was used here in the absence of published experimental data on the system. Preliminary results (*24*) of an investigation in this laboratory by the method of McBain and Liu (*11*) of the actual diffusivity of sulfur dioxide in water at concentrations of 1 to 6 wt. % are only slightly lower than the above given value. This investigation is being extended to lower sulfur dioxide concentrations such as exist throughout most sulfur dioxide absorbers since the proportion of ionized sulfur dioxide increases rapidly with dilution and may change materially the effective diffusivity. The

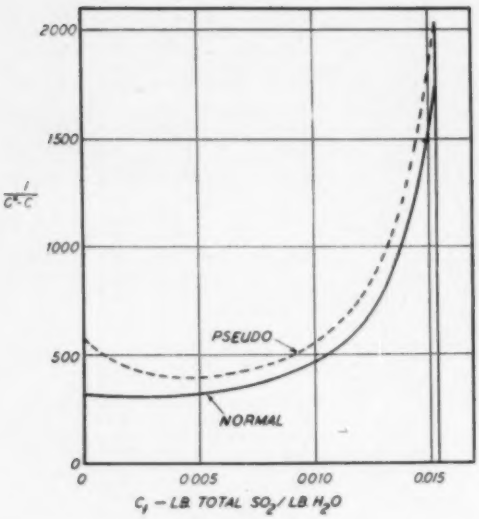

Fig. 4. Plot for graphical integration to evaluate normal and pseudo number of transfer units.

predicted H_L values are plotted as solid lines against temperature in Figures 7 and 8. The corresponding line for $L = 7500$ would lie about 10% higher.

Values of H_G were predicted for each of the flow conditions reported in Table 2 using the equation for $k_G a$ recommended by Whitney and Vivian (*30*). Predictions were made for the top of the tower where the equation reduces to the following form which is independent of temperature:

$$H_G = \frac{G}{M k_G a} = 1.233 \frac{G^{.8}}{L^{.8}} \qquad (11)$$

The predicted values ranged from 0.66 to 0.79 ft., which are approximately twice the heights expected from the results of Doherty and Johnson (*17*) on the absorption of ammonia from air into dilute sulfuric acid. However, end effects may have been abnormally high in their acid tower which had only 16 in. of 1-in. rings.

The predicted values of H_{OL} are obtained by combining H_L and H_G according to Equation (9). This has been done graphically in Figures 5 and 6 for the two temperature limits of 18° C. and 31° C. using $L = 5000$ and an average value of $H_G = 0.7$ in each case.

Correlation of Heights of Transfer Units

The experimental normal H_{OL} values are plotted vs. the normal effective L/mG in Figure 5 along with solid lines representing the predicted values. The points scatter considerably, in part due to the relatively close approach to equilibrium in this tower which magnifies the importance of errors in determining compositions and temperatures. The points generally fall above the predicted lines, indicating that the latter are too optimistic if used with normal N_{OL} values. It is difficult to draw conclusions from this plot as to the effect of temperature or liquor rate, other than as these factors affect L/mG. There is a generally upward trend in H_{OL} with increase in L/mG as would be expected.

Certain of the results of Whitney and Vivian (*30*) with 2 ft. of 1-in. rings for the same range of liquor rates and for the approximate extreme limits of average water temperatures used in this investigation have been recalculated to the H_{OL} basis and are plotted in the Figure 5. In this case the L/mG's were determined directly from the average slopes of the equilibrium and operating lines since these did not change greatly. The general agreement between the two sets of data with a ten-fold difference in depth of packing is excellent, and may reflect the careful elimination of end effects in the shorter tower.

The observed pseudo H'_{OL} values are plotted vs. the pseudoeffective $L/m'G$ in Figure 6 along with predicted values as shown by the two solid lines. The points are bunched more closely when plotted on the pseudo basis, but there is still considerable scattering. It is significant that in this case the predicted H_{OL} lines pass directly through the experimental points.

The normal H_L's were calculated from the observed normal H_{OL}'s and predicted H_G's by Equation (8), and are plotted vs. temperature in Figure 7 along with the predicted values of H_L. The parameter of liquor rate is not shown since the predicted variation in H_L resulting therefrom is only 10% for the range of flows utilized, and any such variation would be completely masked by the random scattering of the data. The observed values range from slightly below the predicted line to considerably above it.

The pseudo H'_L's were calculated and plotted against temperature in the same manner in Figure 8 along with the predicted curve and a few pseudopoints recalculated from Whitney and Vivian (*30*) for the same range of liquor and gas rates. A decrease in pseudo H'_L

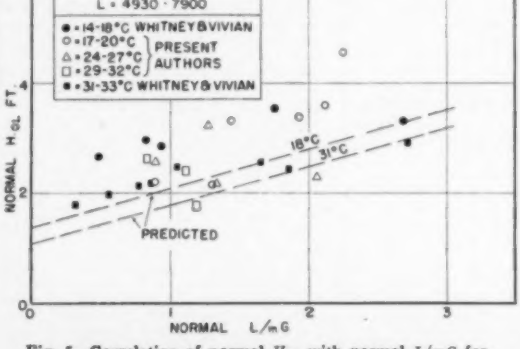

Fig. 5. Correlation of normal H_{OL} with normal L/mG for absorption of sulfur dioxide in water.

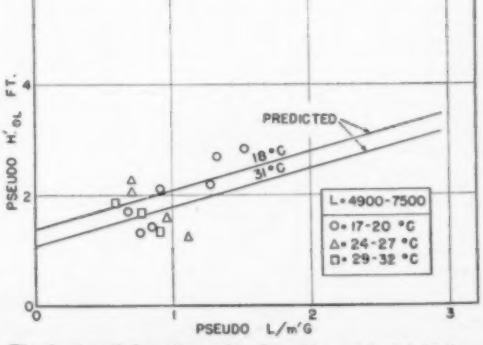

Fig. 6. Correlation of pseudo H'_{OL} with pseudo $L/m'G$ for absorption of sulfur dioxide in water.

with temperature is evident. The experimental points fall more or less evenly above and below the predicted line, as do the points from the data of Whitney and Vivian.

The points in Figures 7 and 8 have been differentiated further according to the liquor concentration at the approximate midpoint of the tower or section of the tower as estimated from the graphical integrations for N_{OL}. Generally, those values representing experiments with the lower midpoint concentrations, and hence with the lower average concentrations throughout the tower, gave considerably higher normal H_L and pseudo H'_L than did the values for the higher midpoint concentrations. Although perhaps fortuitously, the runs with lower average liquor concentrations were fitted better by the pseudoplot, while those with the higher average liquor concentrations were more nearly in agreement with the normal plot. Somewhat the same trend is observed between the results obtained for the bottom and top sections of the tower in run 27 in Table 2.

Summary

1. Mass-transfer rates for absorption of sulfur dioxide from air into water have been determined using a semiworks scale packed tower operating in the commercial range of flow rates to absorb nearly completely the influent sulfur dioxide while simultaneously producing 60 to 97% saturated solutions of sulfurous acid.

2. Since phase equilibrium was rather closely approached in the experiments, proper calculation of results required use of the best possible equilibrium data. Therefore, practically all available equilibrium data for the system sulfur dioxide-water within the range of probable absorption conditions have been closely studied, correlated, and smoothed by use of effective mean ionic activity coefficients by a procedure similar to that suggested by Johnstone and Leppla. Relations are recommended which represent the equilibria between sulfur dioxide in a gas phase and in a water solution between 0 and 50° C. and between 0 and 800 mm. Hg. partial pressure of sulfur dioxide.

3. Experimental data have been calculated in terms of values of both the normal and also the pseudo *H.T.U.* The latter values correspond to the pseudoequilibrium and operating lines suggested by Vivian and Whitney for use with systems in which the solute reacts chemically with the solvent at a rate which is inappreciable in the time required to diffuse through the liquid films but which is fast enough to give essentially complete reaction in the bulk of the liquid beyond the film. It is found that the results are correlated considerably better by the experimental pseudo than by the experimental normal values for heights of transfer units.

4. The mass-transfer data now reported appear to be directly and safely applicable to design of appropriate large-scale sulfur dioxide absorption equipment. The present results indicate that data carefully taken on small-scale laboratory equipment appear to be equally reliable provided that end effects are suitably allowed for or eliminated.

Acknowledgment

The authors wish to express their sincere appreciation to the G. D. Jenssen Co., Inc., for providing the stainless steel tower and other equipment; to the Great Western division of the Dow Chemical Co. for supplying sulfur dioxide in considerable quantity; to Messrs. P. F. Ticer, Henry Toellner, and John Sundling for their material aid in the constructional or experimental work; to the Engineering Experiment Station of the University of Washington for grants of Research Fellowships to D. A. Pearson and L. A. Lundberg, and to R. P. Whitney and J. E. Vivian for providing a complete copy of their manuscript.

Notation

c = concentration of sulfur dioxide in liquid, g.moles/1000 g. water

C = concentration of sulfur dioxide in liquid, lb./lb. water

C^* = equilibrium concentration of sulfur dioxide in liquid, lb./lb. water

G = mass velocity of gas, lb./(hr.)(sq.ft. of tower cross section)

H = Henry's law constant, g. moles/(1000 g. water)(mm. Hg. partial pressure)

H_C = 0.06406 H, lb./(lb. water)(mm. Hg. partial pressure)

H_G = height of gas-phase transfer unit, ft.

H_L = height of liquid-phase transfer unit, ft.

H_{OG} = height of over-all gas-phase transfer unit, ft.

H_{OL} = height of over-all liquid-phase transfer unit, ft.

K = ionization constant for sulfurous acid, g.moles/1000 g. water (*See* Eq. (4))

K_C = 0.06406 K, lb./lb. water

k_Ga = gas-phase mass-transfer coefficient, lb. moles/(hr.)(cu.ft.)(atm.)

K_Ga = over-all gas-phase mass-transfer coefficient, lb. moles/(hr.)(cu.ft.)(atm.)

k_La = liquid-phase mass-transfer coefficient, lb. moles/(hr.)(cu.ft.)(lb. mole/cu.ft.)

K_La = over-all liquid-phase mass-transfer coefficient, lb. moles/(hr.)(cu.ft.)(lb. mole/cu.ft.)

L = liquor rate, lb./(hr.)(sq.ft. of tower cross section)

L/mG = ratio of slope of operating to slope of equilibrium line, dimensionless

M = average molecular weight of gas stream

N_{OG} = number of transfer units based on over-all gas concentrations, dimensionless

N_{OL} = number of transfer units based on over-all liquor concentrations, dimensionless

p = partial pressure of sulfur dioxide, mm. Hg.

p^* = equilibrium partial pressure of sulfur dioxide, mm. Hg.

P = total pressure, mm. Hg.

P_w = vapor pressure of water, mm. Hg.

t = temperature of liquor, ° C.

T = temperature of liquor, ° K.

Y = moles SO_2/mole dry air

Z = depth of packing, ft.

γ_t = mean or effective mean ionic activity coefficient, dimensionless

μ = liquid viscosity, lb./(hr.)(ft.)

ρ = liquid density, lb./cu.ft.

SUBSCRIPTS:

t = total sulfur dioxide

u = nonionized sulfur dioxide

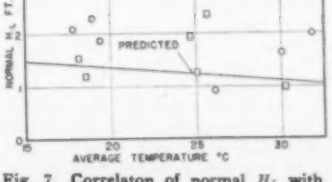

Fig. 7. Correlaton of normal H_L with temperature for absorption of sulfur dioxide in water.

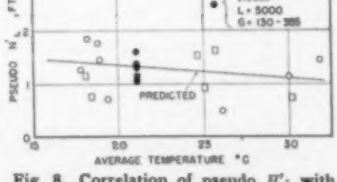

Fig. 8. Correlation of pseudo H'_L with temperature for absorption of sulfur dioxide in water.

i = ionized sulfur dioxide
$_1$ = condition at bottom of packed section
$_2$ = condition at top of packed section

SUPERSCRIPTS:

$'$ = pseudo values

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Discussion

R. S. Sunderlin (Eston Chemicals, Inc., Los Angeles, Calif.): This problem on the absorption of sulfur dioxide in water is of increasing importance, not only to producers of liquid sulfur dioxide but also to users as well—especially here in Los Angeles County.

A few questions are of importance to me: Has the presence of SO_3 or H_2SO_4 mist in the absorber feed gas any effect on the value of C_i in your correlation of equilibrium data? It would seem that, although the majority of the SO_3—H_2SO_4 fog passes on through the tower unabsorbed, any small concentration of sulfuric acid would provide sufficient hydrogen ions to repress appreciably the ionization of sulfurous acid. If this is true, your data are subject to correction since you were working with straight SO_2—air mixtures.

Also, have you considered the effect on absorption rate of sublimed sulfur coatings which are always present on commercial SO_2 absorber packings?

It would also be of practical interest to know the effect of higher inlet gas temperatures, say 40 or 50° C. It is no doubt justifiable to assume instantaneous humidification in your tower as it was operated, but on the other hand it is my experience that most towers are taking feed gas from sulfur burners in the range of 35-50° C.

F. B. West: With regard to question number one, the effect of absorbing any SO_3 from the gas would be to produce sulfuric acid and additional hydrogen ions. This would repress the solubility of the SO_2 due to decreasing its degree of ionization. One should be able to calculate the effect if one knew how much SO_3 was absorbed. In answer to question two, we have not discharged the rings since beginning the investigation, but we have observed no such coating on the packing through windows in the tower.

Your third question refers to the effect of higher inlet gas temperatures. In our calculations we made the arbitrary assumption that the inlet gas would be cooled and humidified instantaneously to equilibrium with the outlet liquor. This was done to simplify the calculations. It should not introduce any particular error, at least in our work with inlet gas temperatures of 30 to 37° C. I do not think that this assumption would be much in error for inlet gases at higher temperatures. Considering that humidification involves primarily a gas phase *H.T.U.*, and that SO_2 absorption involves both a gas phase *H.T.U.* and an unusually large liquid phase *H.T.U.*, the first SO_2 absorption transfer unit should be equivalent to several humidification transfer units. As a result the higher inlet gas temperatures should not affect the results much except as they affect the outlet liquor temperature. This, however, is simply my opinion. We have no experimental data on this point.

Fred Hartley (Union Oil Company of California, Los Angeles, Calif.): Your paper dealt with the absorption of SO_2 in the range of 7 to 15 mole %. The oil industry is concerned with SO_2 removal from stack gases in which the SO_2 concentration varies between 0.1 and 0.3 mole %. Can you give us an idea of the volume of water required to treat, say, 400,000 std.cu.ft./min. of such stack gas to dissolve the SO_2 with the degree of efficiency referred to in your paper?

F. B. West: I cannot give you a direct answer on that. In our 25 to 32° C. runs we used liquor rates of 5000 to 7500 lb./(sq.ft.)(hr.) and gas rates of the order of 210 lb./(sq.ft.)(hr.). The volume of water required to absorb the concentrations you quote would be much less in proportion for comparable temperatures due to the low slope of the equilibrium line in this region. The low slope is due to the degree of ionization being of the order of 70% or so in this region compared with about 25% for our higher concentrations. You could, therefore, use proportionately less water, but I could not say how much less.

Fred Hartley: I understand the Battersea power station in London, England, uses huge volumes of water to scrub the stack gas for SO_2 removal. Do your data indicate that the volume of water required would be less?

F. B. West: We have no experimental data to back up my opinion that proportionately less water could be used than in our investigation. One run has been made at a much lower SO_2 concentration, but the results are not yet available. We are interested in extending our investigation to conditions where the chemical reaction will be more important, which it should be at these low concentrations. It may be that the treatment of Whitney and Vivian is not conservative enough when 80 to 90% of the dissolved SO_2 is ionized at chemical equilibrium. We have no data on this point as yet.

(Presented at Los Angeles (Calif.) Meeting.)

AN ALGEBRAIC SOLUTION OF McCABE-THIELE DIAGRAM

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Rothschild Oil Company, Santa Fe Springs, California

MUCH study has been devoted by some to the correlation of design variables with efficiency data of fractionation tower trays (*1-3, 6, 9, 13, 15*). Others have studied the effects of operating variables (i.e., vapor velocities, liquid loads, and reflux ratios) on tray efficiencies (*2, 5, 9, 12*).

In attempting to evaluate such studies, or in undertaking further research work, it is necessary to have an algebraically exact method of calculating individual tray efficiencies as well as sectional efficiencies. The method should be one that lends itself to many repetitive calculations and which permits precise duplication of results. Since investigations in this field are usually undertaken with binary mixtures, the method must be applicable to binary fractionation.

The McCabe-Thiele diagram (*7*), even with large 3- to 4-ft. plots, does not yield duplicable results. The Fenske equation (*4*) is limited to cases of total reflux. The Smoker Equation (14) and plate-to-plate calculations are tedious.

This paper presents an algebraic solution of the McCabe-Thiele method which lends itself to repetitive, "formsheet" calculations and which avoids diagram drafting errors. The method was primarily and specifically derived for use in experimental studies involving a great number of efficiency calculations.

Preliminary Data and Assumptions

It is assumed that vapor-liquid equilibrium data are available in the X-Y form, or can be derived from relative volatilities, partial pressures, or other data. For illustrative purposes, this paper will use data for the system acetone-ethanol at atmospheric pressure (*10*).

TABLE 1.—VAPOR-LIQUID EQUILIBRIUM DATA FOR ACETONE-ETHANOL

X (mole fraction acetone in liquid)	Y (mole fraction acetone in vapor)
0.000	0.000
0.100	0.262
0.200	0.417
0.300	0.524
0.400	0.605
0.500	0.674
0.600	0.739
0.700	0.802
0.800	0.865
0.900	0.929
1.000	1.000

It is assumed that the flows and analyses indicated below are available. It is also assumed that samples are obtained from tray downcomers and represent the liquid leaving the trays.

Derivation of Method

Figure 1 presents the usual X-Y plot of the data in Table 1. Trays are numbered from top to bottom. When the overhead vapors are totally condensed and divided into reflux and draw-off, X_D represents liquid composition entering the top tray, and is equal to the vapor leaving that tray. Partial condensation of overhead vapors results in additional fractionation and X_D is no longer equal to the overhead vapor. In both cases, X_D can be obtained by sampling the reflux. However, since total condensation is more common in experimental studies, partial condensation is not considered here. Point X_B represents the tower bottoms composition and is obtained by sampling at a point where the liquid has been reboiler recycled. Points X_1^E, X_2^E, etc., represent actual liquid entering the trays, and X_1^L, X_2^L, etc., represent actual liquid leaving the trays. Obviously, $X_1^L = X_2^E$, $X_2^L = X_3^E$, etc.

The lines X_D-X_i and X_i-X_B represent liquid and vapor compositions at any point within the tower, and their slopes are fixed by the internal reflux ratio, L/V, in their respective column sections. X_i is the intersection of the two operating lines. The total liquid composition change a tray can accom-

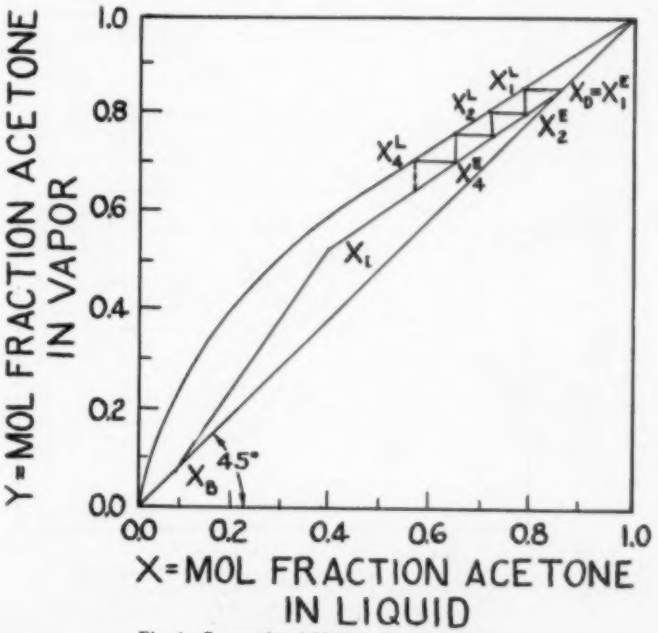

Fig. 1. Conventional McCabe-Thiele diagram.

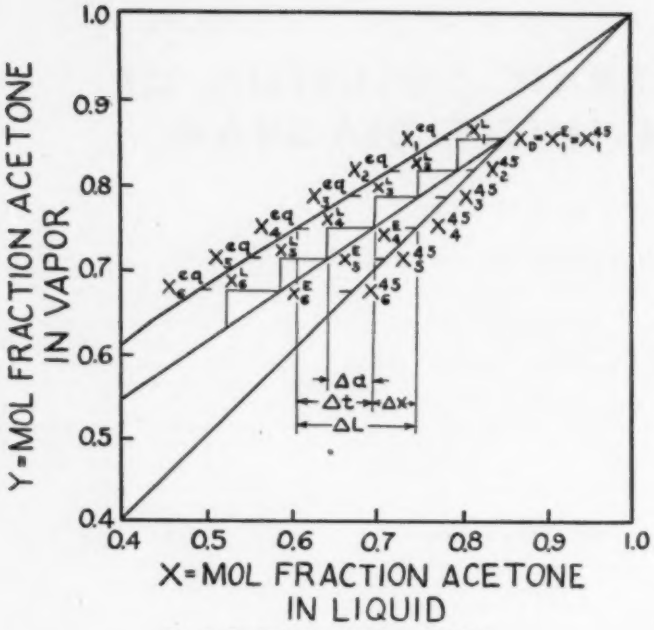

Fig. 2. Typical operation in rectification.

plish at a given L/V is represented by the horizontal distance from the operating line to the equilibrium curve.

Figure 2 depicts more usual conditions for the rectification zone. Points X_1^L, X_2^L, etc., still represent actual liquid compositions leaving the trays. Points X_1^{eq}, X_2^{eq}, etc. (on the equilibrium curve) represent the theoretical liquid compositions which trays 1 and 2 might reach if they were 100% efficient. Thus, distances $X_1^E - X_1^L$, $X_2^E - X_2^L$, etc., represent actual liquid composition changes and are denoted as Δa. Distances $X_1^E - X_1^{eq}$, $X_2^E - X_2^{eq}$, etc., represent the theoretical maximum changes which trays 1 and 2 could accomplish and are denoted as Δt. Therefore, η_n, the Murphree liquid efficiency (8) for tray n can be written as $(\Delta a_n/\Delta t_n)100$.

The points X_1^{45}, X_2^{45}, etc., represent intersections of the 45° diagonal with horizontal extensions of lines $X_1^{eq} \cdot X_1^L \cdot X_1^E$, $X_2^{eq} \cdot X_2^L \cdot X_2^E$, etc. The distances ΔX_n and ΔL_n represent $X_n^{45} - X_n^E$ and $X_n^{45} - X_n^{eq}$, respectively.

Figure 2 reveals that:

$$\eta_n = (\Delta a_n/\Delta t_n)100 \qquad (1)$$

$$= \frac{X_n^E - X_n^L}{\Delta L_n - \Delta X_n} \times 100 \qquad (2)$$

X_n^E and X_n^L are obtained by downcomer sampling and Δa_n is available. However, ΔL_n and ΔX_n are still lacking. Since ΔL_n represents the horizontal distance between the equilibrium curve and the 45° diagonal, it is independent of the reflux ratio, L/V, and is a constant at any point n. ΔL_n values can be calculated as follows:

$$\Delta L_n = X_n^{45} - X_n^{eq} \qquad (3)$$

$$= Y_n^{eq} - X_n^{eq} \qquad (4)$$

Using the X-Y data in Table 1, ΔL_n values were obtained by Equation (4) and plotted against $X_n^{45} = Y_n^{eq}$. Interpolation from that plot yielded additional values for Table 2.

The interpolation procedure for obtaining Table 2 should be carefully executed and preferably by a single individual. Table 2 is merely another method of tabulating vapor-liquid equilibrium data, i.e., Y vs. Y-X. Increments of X_n^{45} should be small enough to exclude need for interpolation. Once compiled to the desired degree of accuracy, Table 2 should be used then in all calculations.

Referring to Figure 3, the two legs of the 45° triangle $X_D \cdot A \cdot X_n^{45}$ are equal, and hence $X_D \cdot A = X_D - X_n^{45}$.

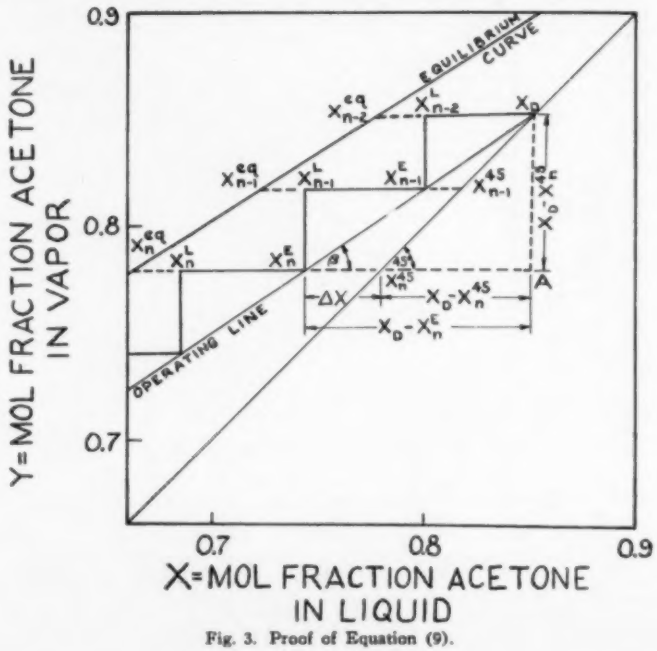

Fig. 3. Proof of Equation (9).

TABLE 2.—VAPOR-LIQUID EQUILIBRIUM DATA IN ΔL FORM

X_n^{45}	ΔL_n	X_n^{45}	ΔL_n
0.100	0.069	0.525	0.224
0.125	0.086	0.550	0.221
0.150	0.102	0.575	0.216
0.175	0.118	0.600	0.209
0.200	0.132	0.625	0.197
0.225	0.145	0.650	0.186
0.250	0.156	0.675	0.175
0.275	0.168	0.700	0.160
0.300	0.178	0.725	0.148
0.325	0.188	0.750	0.133
0.350	0.197	0.775	0.117
0.375	0.205	0.800	0.103
0.400	0.213	0.825	0.088
0.425	0.218	0.850	0.073
0.450	0.221	0.875	0.058
0.475	0.224	0.900	0.046
0.500	0.225		

Since the operating line slope is equal to the reflux ratio, L_R/V_R:*

$$\text{Slope} = L_R/V_R \quad (5)$$

$$L_R/V_R = \text{tangent} < \beta \quad (6)$$

$$= \frac{X_D - X_n^{45}}{X_D - X_n^E} \quad (7)$$

$$= \frac{X_D - (X_n^E + \Delta X_n)}{X_D - X_n^E} \quad (8)$$

$$\Delta X_n = (X_D - X_n^E)(1 - L_R/V_R) \quad (9)$$

The calculation of a Murphree liquid efficiency for tray n in the rectifying zone is summarized below:

Given:

a. Equilibrium data in the form of Table 2.
b. Internal reflux ratio, L_R/V_R.
c. Composition of liquid entering and leaving tray n.
d. Top distillate composition, X_D.

Step 1:

$$\Delta a_n = X_n^E - X_n^L \quad (10)$$

Step 2:

$$\Delta X_n = (X_D - X_n^E)(1 - L_R/V_R) \quad (11)$$

Step 3:

$$X_n^{45} = X_n^E + \Delta X_n \quad (12)$$

Step 4:

$$\Delta L_n = f(X_n^{45}) \quad (13)$$

$f(X_n^{45})$ = function of X_n^{45} obtained from Table 2

Step 5:

$$\Delta t_n = \Delta L_n - \Delta X_n \quad (14)$$

Step 6:

$$\eta_n = (\Delta a_n/\Delta t_n)100 \quad (15)$$

Analogous treatment of the stripping zone yields the following procedure:

Step 1:

$$\Delta a_n = X_n^E - X_n^L \quad (16)$$

Step 2:

$$\Delta X_n = (X_n^E - X_B)(L_B/V_B - 1) \quad (17)$$

Step 3:

$$X_n^{45} = X_n^E + \Delta X_n \quad (18)$$

Step 4:

$$\Delta L_n = f(X_n^{45}) \quad (19)$$

Step 5:

$$\Delta t_n = \Delta L_n - \Delta X_n \quad (20)$$

Step 6:

$$\eta_n = (\Delta a_n/\Delta t_n)100 \quad (21)$$

The difference in rectifying or stripping zone equations lies in Step 2.

Thus far, the method deals with individual tray efficiencies. In practice, it is difficult to obtain accurate downcomer samples, and an individual tray efficiency has little meaning unless the experimental tower has 15-20 plates and an average efficiency is determined. Adjacent trays may vary as much as 10%-15% under seemingly excellent conditions of dynamic stability. One solution is to use an average efficiency as the criterion of performance.

A more reliable criterion is a sec-

* The scope of this paper does not include the methods of determining internal reflux ratios.

Problem A: Calculate individual tray efficiencies of (1) trays 1, 2, 3 in rectifying zone, and (2) trays 7, 8, 9 in stripping zone.

(1) Tray	X_n^E	$X_D - X_n^E$	ΔX_n	X_n^{45}	ΔL_n	Δt_n	Δa_n	%
1	0.800	0.000	0.000	0.800	0.103	0.103	0.080	77.7
2	0.720	0.080	0.034	0.754	0.130	0.096	0.070	72.9
3	0.650	0.150	0.065	0.715	0.153	0.088	0.070	79.5
4	0.580							

Average = 76.7%

(2) Tray	X_n^E	$X_n^E - X_B$	ΔX_n	X_n^{45}	ΔL_n	Δt_n	Δa_n	%
7	0.430	0.330	0.142	0.572	0.217	0.075	0.058	77.4
8	0.372	0.272	0.117	0.489	0.224	0.107	0.087	81.3
9	0.285	0.185	0.080	0.365	0.200	0.120	0.100	83.3
B	0.185							

Average = 80.7%

Problem B: Calculate sectional efficiencies from (1) top-tray inlet to tray-3 exit, and (2) from tray-7 inlet to tray-9 exit.

(1) Tray	X_n^E	$X_D - X_n^E$	ΔX_n	X_n^{45}	ΔL_n	Δt_n
1	0.800	0.000	0.000	0.800	0.103	0.103
2	0.697	0.103	0.044	0.741	0.138	0.094
3	0.603	0.197	0.085	0.688	0.167	0.082
4	0.521					

Tray 3 actual exit composition is 0.580. Thus,

$$\text{Theoretical trays} = 2 + \frac{0.603 - 0.580}{0.603 - 0.521} = 2.280$$

$$\text{Actual trays} = 3.000$$

$$\eta = \frac{2.280}{3.000} \times 100 = 76.0\%$$

(2) Tray	X_n^E	$X_n^E - X_B$	ΔX_n	X_n^{45}	ΔL_n	Δt_n
7	0.430	0.330	0.142	0.572	0.217	0.075
8	0.355	0.255	0.110	0.465	0.223	0.113
9	0.242	0.142	0.061	0.303	0.179	0.118
10	0.124					

$$\text{Theoretical trays} = 2 + \frac{0.242 - 0.185}{0.242 - 0.124} = 2.480$$

$$\text{Actual trays} = 3.000$$

$$\eta = \frac{2.480}{3.000} \times 100 = 82.7\%$$

Problem C: Calculate sectional efficiency from (1) top-tray inlet to bottom-tray exit, and (2) from top-tray inlet to reboiler-cycled bottoms.

Since feed enters as a saturated liquid, $q = 1$, and from Equation (34):

$$X_A = X_F = 0.450$$

If feed enters at some other thermal condition, then $q \neq 1$, and L_B/D, which is needed for Equation (34), would be obtained from a material balance as follows:

$$L_B + D = V_B$$

$$= L_B(V_B/L_B)$$

$$L_B/D = \frac{1}{V_B/L_B - 1}$$

(1) Tray	X_n^E	$X_D - X_n^E$	ΔX_n	X_n^{45}	ΔL_n	Δt_n
1	0.800	0.000	0.000	0.800	0.103	0.103
2	0.697	0.103	0.044	0.741	0.138	0.094
3	0.603	0.197	0.085	0.688	0.167	0.082
4	0.521	0.279	0.120	0.641	0.182	0.062
5	0.459	0.341	0.147	0.606	0.205	0.058
6	0.401					

$$\text{Rectifying theoretical trays} = 4 + \frac{0.459 - 0.450}{0.459 - 0.401} = 4.155$$

Tray	X_n^E	$X_n^E - X_B$	ΔX_n	X_n^{45}	ΔL_n	Δt_n
1	0.450	0.350	0.151	0.601	0.208	0.057
2	0.393	0.293	0.126	0.519	0.224	0.098
3	0.295	0.195	0.084	0.379	0.206	0.122
4	0.173					

Stripping theoretical trays $= 2 + \dfrac{0.295 - 0.185}{0.295 - 0.173} = 2.900$

$$\eta = \frac{4.155 + 2.900}{9.000} \times 100$$

$$= 78.5\%$$

To obtain a sectional efficiency including the reboiler, another step is needed:

(2) Tray	X_n^E	$X_n^E - X_B$	ΔX_n	X_n^{eq}	ΔL_n	Δt_n
4	0.173	0.073	0.031	0.204	0.134	0.103
5	0.070					

Stripping theoretical trays $= 3 + \dfrac{0.173 - 0.100}{0.173 - 0.070} = 3.720$

$$\eta = \frac{4.155 + 3.720}{10.000} \times 100 = 78.8\%$$

Problem D: The method can also be adapted to design work. If all the trays in the tower to be designed are the same, the number of theoretical trays is determined as outlined above for a sectional efficiency. Using a known, or assumed efficiency, η, the number of actual trays required is obtained from:

$$\text{Actual trays} = \text{theoretical trays}/\eta$$

If all the trays in the tower are not the same, and therefore do not have the same individual efficiencies, the procedure would be:

$$\Delta X_n = (X_D - X_n^E)(1 - L_R/V_R)$$

$$X_n^{eq} = X_n^E + \Delta X_n$$

$$\Delta L_n = f(X_n^{eq})$$

$$\Delta t_n = \Delta L_n - \Delta X_n$$

$$\Delta a_n = \eta_n(\Delta t_n)$$

where η is assumed or known for that tray.

$$X^E_{n-1} = X_n^L = X_n^E + \Delta a_n$$

etc.

tional efficiency. The calculation of a sectional efficiency is a determination of the theoretical plates required to go from one actual analysis to the analysis at the other end of the section. Starting at the top:

1. $X_n^E = X_D$ (22)
2. $\Delta X_n = 0$ (since $X_D - X_n^E = 0$ at top tray) (23)
3. $X_n^{eq} = X_n^E + 0 = X_n^E$ (24)
4. $\Delta L_n = f(X_n^{eq})$ (25)
5. $\Delta t_n = \Delta L_n - 0 = \Delta L_n$ (26)

The theoretical composition change for the top tray having been determined, it is subtracted from X_n^E to obtain X^E_{n+1} and the procedure is continued.

1. $X^E_{n-1} = X_n^E - \Delta t_n$ (27)
2. $\Delta X_{n-1} = (X_D - X^E_{n-1})(1 - L_R/V_R)$ (28)
3. $X^{eq}_{n-1} = X^E_{n-1} + \Delta X_{n-1}$ (29)
4. $\Delta L_{n-1} = f(X^{eq}_{n-1})$ (30)
5. $\Delta t_{n-1} = \Delta L_{n-1} - \Delta X_{n-1}$ (31)

For the third tray:

1. $X^E_{n-2} = X^E_{n-1} - \Delta t_{n-1}$ (32)
2. Etc.

This stepwise method is continued until the analysis of liquid leaving the last tray of the section is reached or passed. If the analysis is passed, the fractional part of that theoretical step is calculated. The number of *actual* trays includes all trays within the tower between the two analyses. The sectional efficiency is:

η = (theoretical trays/actual trays) 100 (33)

If the reboiler is in the chosen section, it is counted as one *actual* tray. However, it is more accurate to avoid such a choice, since reboiler efficiency is usually higher than tray efficiency.

If the section includes the feed tray, the procedure is as follows:

a. Determine the theoretical trays to reach the intersection of the operating lines, X_i.
b. Starting at X_i, and using the stripping zone equations, calculate the theoretical trays to reach the liquid analysis leaving the section's last tray (or the bottoms analysis if reboiler is included).
c. X_i may be determined from (11):

$$X_i = \frac{X_F(L_R/D + 1) + X_B(q - 1)}{q + L_R/D} \quad (34)$$

where:

X_F = mole fraction of more volatile component in total feed (liquid plus vapor)
L_R = rectifying zone liquid reflux
q = heat needed to bring 1 mole of feed to the saturated vapor state divided by heat of vaporization
d. η = (theoretical trays/actual trays) 100 (35)

Example Calculations

Data:

$X_D = 0.800 = X_1^E$
$X_1^L = 0.720$
$X_2^L = 0.650$
$X_3^L = 0.580$
$X_4^L = 0.430$
$X_5^L = 0.372$
$X_6^L = 0.285$
$X_7^L = 0.185 = X_B$
$X_B = 0.100$
$X_F = 0.450$ (feed enters in saturated liquid state)
$L_R/V_R = 0.57$ $(1 - L_R/V_R = 0.43)$
$L_S/V_S = 1.43$ $(L_S/V_S - 1 = 0.43)$

Notation

X = mole fraction of more volatile component in liquid
Y = mole fraction of more volatile component in vapor
L = internal liquid downflow in moles/unit feed
V = internal vapor flow in moles/unit feed
D = overhead draw-off in moles/unit feed
n = any tray
Δa = actual tray liquid composition change
Δt = theoretically attainable liquid change for tray
ΔX = horizontal distance from operating line to 45° diagonal
ΔL = horizontal distance from equilibrium line to 45° diagonal
η = Murphree tray liquid efficiency, %

Subscripts:

1,2,3 = trays numbered from top to bottom
D = overhead draw-off
B = tower bottoms
R = rectifying zone
S = stripping zone
F = total feed (liquid and vapor)
i = intersection of operating lines
b = bottom tray
n = any tray

Superscripts:

E = entering tray
L = leaving tray
eq = lying on equilibrium curve
45 = lying on 45° diagonal

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LETTER TO THE EDITOR

LIQUID METAL HEAT-TRANSFER COEFFICIENTS

Sir:

The paper, "Liquid Metal Heat-Transfer Coefficients," in the February number is an excellent example of the kind of research being done in the field of transfer processes—undoubtedly good work, but largely wasted because the fundamental work has not yet been done. As Gilliland points out in the January number, "our research problem should be able to develop a more fundamental approach to the problem."

So far as the basic physics of the problem is concerned we have not advanced beyond Reynolds' concept published in 1874, and so well illustrated by Lyon's Figure 1. Our progress has been along the lines of describing the concept and devising approximations, such as the core, film and buffer zone model introduced in 1930 by Eagle and Ferguson, for which mathematical expressions can be more easily obtained.

Gilliland seems to advocate abandoning the laminar film hypothesis, saying "Turbulence is undoubtedly a phenomenon that increases progressively from the wall—," but that he really means this is not clear, since the rest of the sentence is "rather than by discrete jumps as implied in a film-core type of concept." The writer is not willing to discard the laminar film hypothesis until there is a good reason for doing so. Considering the difficulties of measuring velocities close to the wall, it may be a long time before there is conclusive experimental proof that turbulence does or does not exist at the wall or close to it.

It is unfortunate that Nikuradse made undisclosed adjustments to his measurements which have caused many later investigators to fall into error; it is not possible to say that Lyon has had this misfortune, since he does not detail how he used Nikuradse's report.

It is not necessary to choose between progressive increase of turbulence and discrete jumps; considering turbulence as a flow mode in which the velocity gradient is less than it would be for laminar flow, the difference between the actual velocity gradient and that calculated for laminar flow may decrease continuously as the wall is approached but become zero at a finite distance from the wall.

Progress in this field will come more rapidly the writer believes when chemical engineers think more often as aeronautical engineers do about turbulence, that turbulence is a mode of fluid motion in which groups of molecules act together. The thing to stress is not the macroscopic disorder, but the submicroscopic order. Chemical engineers are too apt to look at the eddying motion as irregular, and contrast it with the assumed regular motion of laminar flow. But this point of view is valid only when we are concerned principally with transfer in the flow direction, for only for velocity in the flow direction do the molecules exhibit correlation in laminar flow. The great contribution of Taylor was his stress on correlation of the fluid particles for velocity at right angles to the flow direction. While aeronautical engineers have adopted Taylor's concepts, in chemical engineering literature Taylor is mentioned chiefly in connection with his independent derivation of an approximate mathematical expression for Reynolds' analogy.

If, following Taylor's lead but using words more familiar to chemical engineers, we think of turbulence in terms of a group of molecules having an average velocity at right angles to the flow direction, the effectiveness of the group is dependent upon two magnitudes, the size of the group and the speed at which it is moving normal to the flow. The size of the group is analogous to the scale of the turbulence, while the speed is related to the intensity. There is some experimental evidence to the effect that the group size decreases continuously from pipe center toward the wall, but that the group speed increases. If this be so, the product of the two factors, which is a measure of the transfer effectiveness, may have a maximum somewhere between the center and the wall, and it may become zero at a finite distance from the wall.

The mixing length theory of Prandtl has some points of similarity to the correlation concept, but taking the mixing length as proportional to the distance from the wall is not justified.

By appropriate mathematical manipulation it is possible to obtain formulas which reproduce experimental results well within their probable error, as shown in the writer's 1937 paper (*Trans. Am. Inst. Chem. Engrs.*, **33**, p. 474), which utilizes the two-factor formulation for turbulence, but does not explain the underlying theory which was not then appreciated.

We are all agreed that momentum, heat and mass transfer are different aspects of a single entity. With isothermal flow of a homogeneous fluid it is possible to balance the heat and mass transfer aspects so that momentum transfer can be studied as though it were taking place alone, but the same cannot be done for heat or mass transfer. It follows that the best way and the only fundamental way to attack the problem is one which will first yield a solution for the momentum transfer. Until we know how the velocity varies with distance from the wall in the simple case all research in transfer must be but a fumbling for isolated facts whose significance when they are found remains unknown.

There does not seem to be much hope in further efforts to study turbulence near a pipe wall with devices such as pitot tubes and hot wires which themselves change the flow conditions. We must use a tool which is sensitive to fluid velocity but to which fluid velocity is insensitive.

Perhaps it would be possible to introduce through the wall of a pipe a stream of alpha particles of known range in the fluid flowing through the pipe; this might be done if the pipe wall had a thin spot and some polonium were brought close to it. The ions formed could be detected downstream. Various experiments might be made with steady and pulsed introduction. For example, one might measure the time interval between the instant of creating ions at a certain point in the flow and the instant at which ions were detected at some other point.

If our Institute had a Committee on Fundamental Research which had the duty of pointing out problems for which solutions are needed and of encouraging work on their solution, this problem of turbulent flow would be the one which the writer would recommend that they put at the top of the list. Certainly our pride in chemical engineering research should not be great while our knowledge of turbulent flow is so incomplete.

Ozone Park, N. Y.
March 6, 1951

Benjamin Miller

THE DESIGN OF A CONTINUOUS COLD RUBBER PROCESS

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ONE of the major accomplishments in the postwar, government-sponsored program of *GR-S* American rubber production was the development of cold rubber. The year 1948 found a substantial portion of the government-owned *GR-S* plants being converted to cold rubber because of its superior properties.

Cold rubber differs from regular *GR-S* "hot" rubber by reason of the lower temperature of polymerization of 41° F. instead of 122° F. The stripping, coagulation and drying procedures remain relatively unchanged. To accomplish the polymerization reaction at the lower temperature while still maintaining the same reaction rates without sacrifice of production capacity necessitates the use of a considerably different polymerization recipe, one that is greatly activated by more potent catalysts or initiators and additional activators.

† A division of the B. F. Goodrich Co.

In 1948, plans were initiated to convert the first half of the government-owned 60,000-ton per year plant at Port Neches, Tex., to cold rubber production. This plant is operated by the B. F. Goodrich Chemical Co., and engineering and design work for this conversion was performed by its engineers. The plant was then polymerizing hot rubber by the continuous method, having successfully converted from the batch process to continuous in 1945; however, early cold rubber development work, both in the pilot plant and other production plants had indicated excessively long induction periods and slow reaction rates which, if not improved, would make continuous cold rubber impractical.

The urgency of the conversion would not permit postponement of work until the obstacles to the continuous process were removed. Realizing the many advantages of continuous polymerization, and believing that development work would eliminate the difficulties with the cold continuous process, Goodrich decided to design the process for initial production on a batch basis with provisions for rapid conversion to continuous as soon as development work indicated such a step was practical. Equipment was designed to perform under either type of operation and piping was designed to permit rapid insertion of "line blinds" and "spool pieces" to convert from one type of operation to the other.

Table 1 presents a typical polymerization recipe for cold rubber.

Figure 1 shows the batch process for polymerizing cold rubber. The feedstocks are charged to the 3750-gal. glass-lined reactors batchwise through feedstock coolers which cool the ingredients to 41° F. by use of refrigerated brine. In order to minimize reactor downtime the ingredients are charged as rapidly as possible. The speed with which this can be done is limited by the size of the charge pumps and, more important, by the permissible cooling capacity of the refrigeration system and the size of the feedstock coolers themselves.

As soon as all the soap solution, activator, butadiene, styrene and modifier are charged, the initiator is added. At this time polymerization of butadiene and styrene starts and proceeds until the desired monomer conversion is reached. To remove the exothermic heat of polymerization a coolant is circulated through the reactor jacket. While cooling tower water was used in hot rubber production, a refrigerated coolant is necessary to maintain the 41° F. polymerization temperature required here. At the desired conversion point the batch is "blown down." This term is a carryover from hot rubber polymerization. At 122° F. the unconverted butadiene exerted enough vapor pressure to permit transfer of the batch from the reactor to the blowdown tank by virtue of the butadiene vapor pressure and the slightly higher elevation of the reactor; however, at 41° F. the butadiene vapor

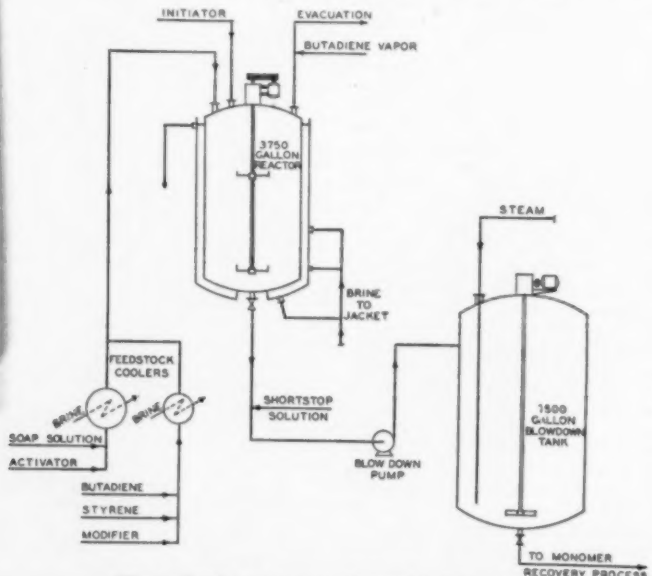

Fig. 1. Batch process for polymerizing cold rubber.

TABLE 1.

Material	Parts per 100 Parts of Monomers
Butadiene	71.00
Styrene	29.00
Cumene hydroperoxide (initiator)	0.10
Sulfole (modifier)	0.16
Dresinate 214	4.70
Trisodium phosphate	0.50
Ferrous sulfate	0.10
Potassium pyrophosphate (activator)	0.20
Glucose	0.80
Water	180.00

pressure is negligible and the batch must be pumped to the blowdown tank. "Shortstop" solution is added at the pump suction to stop the polymerization reaction. Simultaneously, with the reactor blowdown, butadiene vapor is admitted at the top of the reactor. The cold reactor walls cause butadiene condensation, the condensate serving to flush the walls of the reactor free of latex, thus preventing freezing on the refrigerated walls. At the conclusion of the blowdown operation, the reactor is evacuated to reduce the amount of reaction inhibiting oxygen in the system. Steam is added to the blowdown tank to heat the latex preparatory to latex stripping and recovery of unreacted monomers.

Figure 2 shows the continuous process for cold rubber production. In this process the hydrocarbon-water emulsion flows continuously through twelve 3750-gal. reactors in series, at the rate such that the hold-up time in the system represents the reaction time of the process. The raw materials are added at constant flow rates to the charge header, the rate of each ingredient being controlled by a flow-controller recorder or proportioning pump in the same manner as in continuous production of hot rubber. Soap solution, initiator, butadiene, styrene, modifier and activator are added to the charge header in that order. The emulsion is then cooled continuously in the feedstock cooler with refrigerated brine. After leaving the charge cooler the emulsion enters the bottom of the first reactor, overflows from the top of the first reactor and on to the second reactor, etc. After leaving the 12th reactor the latex passes through ten "displacement tubes" in series, latex entering the bottom of the tube and overflowing from the top. The tubes are 18 in. in diameter and 30 ft. high and have a volume equivalent to about one tenth of one of the large reactors. The primary purpose of these tubes is to provide small volume vessels which are representative of small increments of the reaction time. Shortstop may be added at the top of any one of the tubes thus providing a simple method of varying the reaction time by small increments when desired without changing flow rates. A back-pressure regulator is provided to assure against butadiene vaporization and to maintain constant flow conditions in the polymerization system. Since the entire system is hydraulically filled, the raw material feed pumps provide the necessary pressure to transfer the latex to the blowdown tanks without the use of the blowdown pump necessary for batch blowdown.

Figure 3 shows a line of reactors used in continuous polymerization. Reactors are insulated with 5 in. of vegetable cork. Due to the relatively large mass of "in process" material involved, the continuous method is definitely limited to processes where frequent changes in product specifications are not necessary and where large capacities are needed.

The selection of refrigeration equipment for the process was influenced markedly by local conditions. The existence of open nonpressure-type jackets on the reactors prevented the use of direct refrigeration with refrigerant in the jacket. This factor plus the availability of 15-lb. exhaust steam at a low cost gave preference to the "package"-type centrifugal machine and 15-lb. steam

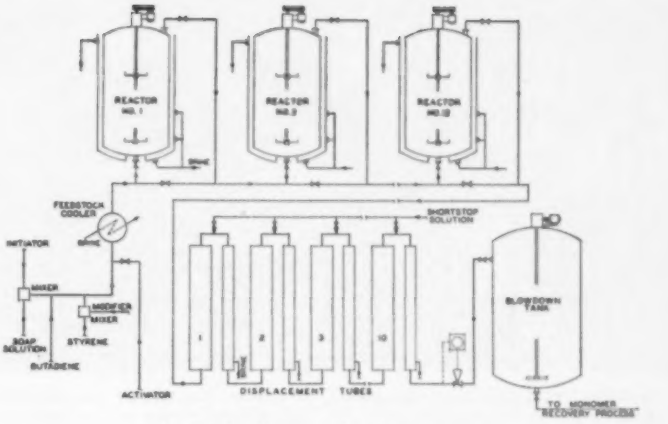

Fig. 2. Continuous cold rubber process.

turbine drive with its inherently low maintenance cost, short refrigerant lines, small floor-space requirements and completely automatic operation. Economical steam-condensing vacuum was determined to be 26 in. Hg. Surface-type steam condensers were used to permit recovery of steam condensate. In an effort to make the refrigeration system independent of an electric power failure, and to furnish balanced steam requirements, brine pumps and condensate return pumps were both steam-turbine driven. To insure dependable steam supply, a steam "loop" was installed to protect against steam line failure.

The selection of refrigeration coolant and refrigeration capacity provided an interesting part of the design. As mentioned previously, the existing reactors had nonpressure-type jackets. These jackets were the only practical means by which heat of polymerization could be removed. Their limited amount of heat-transfer surface established the heat-transfer characteristics and temperature necessary for the refrigeration coolant.

Because of the pseudoplastic characteristics of *GR-S* latex and high fouling factors, it would be difficult if not impossible to calculate accurately the reactor heat-transfer coefficient or extrapolate it from pilot plant data and theoretical latex properties. Fortunately several other plants had operated production reactors on cold rubber and data on these runs were available. By subtracting theoretical jacket film resistances, jacket fouling factors and wall resistances from the actual over-all heat-transfer resistance, the true latex film coefficient was calculated. The reactors were originally equipped with jacket-agitating nozzles and consequently by proper sizing, it was possible to increase jacket velocities to those

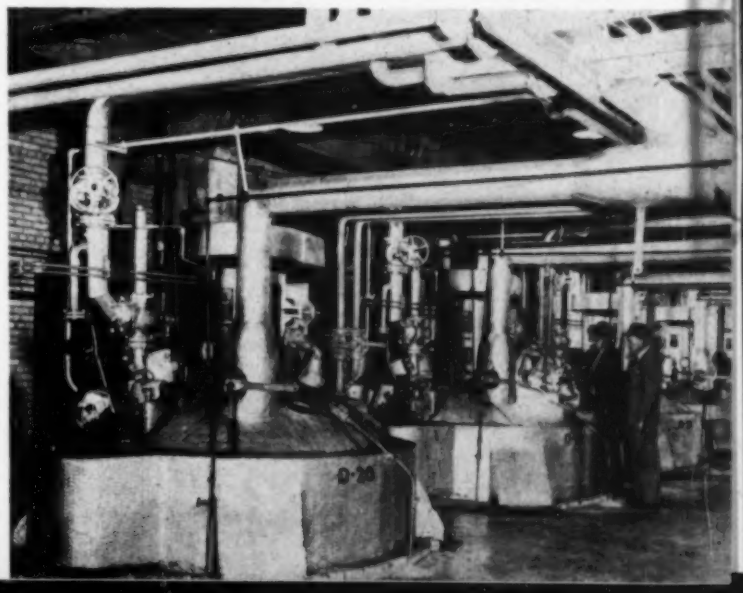

Fig. 3. 3750-gal. polymerization ► reactors.

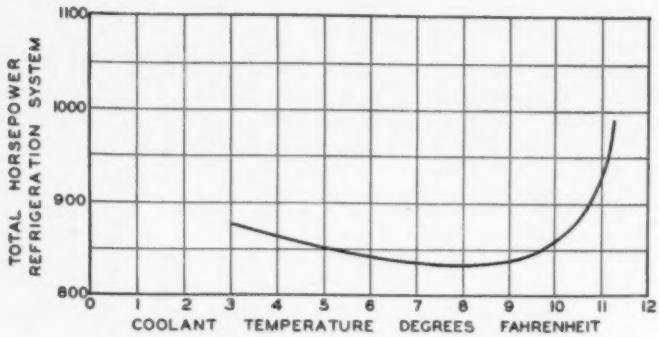

Fig. 4. Refrigeration horsepower vs. coolant temperature.

optimum for the cold rubber design. The rate of polymerization conversion and heat evolution in the cold rubber reaction is relatively constant throughout the cycle. There is, however, a point of maximum latex viscosity toward the end of the reaction time, which makes the heat-transfer coefficient lowest at that point. Consequently minimum brine temperature must be maintained for this part of the reaction cycle.

Theoretical coolant temperatures were calculated for various coolant properties. Results of these studies are presented in Table 2.

The obvious advantage of calcium chloride brine from the standpoint of heat transfer, safety and economy is somewhat offset by its increased corrosive properties; however, after inspection of numerous brine systems, it was decided that proper use of corrosion inhibitors would minimize this disadvantage and calcium chloride brine was chosen as the coolant.

A certain amount of flexibility was possible in designing the refrigeration system by variation of brine circulation rates and the interdependent brine temperature. Figure 4 shows the results of this study. The optimum cold brine temperature was 8° F. At brine temperature lower than the optimum, refrigeration machine horsepower increases at a greater rate than brine pump horsepower decreases, while at temperatures above the optimum, brine pump horsepower increases much faster than refrigeration machine horsepower decreases. The point of minimum equipment cost is also coincident with the point of minimum horsepower expenditure.

A 5° F. brine temperature was chosen for refrigeration specifications thus providing a potential 20% heat-transfer design safety factor at not too great a deviation from the most economical brine temperature.

Calculation of the refrigeration capacity required for a 30,000-ton per year production line yielded the results shown in Table 3.

Heat of polymerization is the exothermic heat liberated during the polymerization reaction. Calculations were based on a 600 B.t.u./lb. value which had been measured previously for the *GR-S* reaction. Heat of agitation is the heat equivalent of horsepower input to the process liquid by the reactor agitators. Heat of brine pumps is the heat equivalent of horsepower input to the brine by these pumps. Heat gain through insulation is small. Insulation thickness was selected to prevent surface condensation and consequent insulation deterioration rather than to provide the optimum heat gain vs. investment economy. Heat removed from charging ingredients is a substantial 20% of the total and will be discussed later. The machines finally selected were three units, each capable of 400 tons of refrigeration at 5° F. brine temperature using Freon 12 refrigerant. Two machines operate regularly while the third machine is a stand-by unit. At the outset of the project it was considered possible that polymerization temperature might drop as low as 0° F. because of further improvement of product by the lower reaction temperatures. The refrigeration machine was therefore designed to permit conversion to operate at 235-ton capacity with −39° F. methylene chloride brine. This would be accomplished by changing turbine governor settings for higher speeds and installation of additional baffles in evaporator heads to compensate for the lower brine flow per machine. Figure 5 shows the area selected for refrigeration equipment location immediately adjacent to the reactor building and on the side nearest other reactor buildings. This permits present reactor operators to attend the refrigeration system integrating the entire cold rubber polymerization process into a closely coordinated system requiring a minimum of additional operating labor over continuous hot rubber. The location also provides additional space for future refrigeration expansion in case of production expansion or further lowering of polymerization temperature. Figure 6 shows one of the refrigeration machines.

The large percentage of the total refrigeration load necessary for cooling charging ingredients forms the basis for one major advantage of the continuous process. To reduce reactor downtime in the batch process, ingredients are charged within a 20-min. interval or about four times as fast as the continuous charging rate. This not only puts an 80% surge demand on refrigeration, but also throws a similar surge on the steam generation unit supplying the turbines and reduces economical balancing of the steam supply in the plant.

The batch process also requires much larger feedstock coolers. These coolers are shell and tube, internal floating head-type heat exchangers with brine inside the tubes and process fluid in the shell. In this way the mass of process fluid left in the shell at the end of the batch is much greater than the mass of cold brine in the tubes and the chance of rupture caused by freezing is minimized. In the design of these heat exchangers

TABLE 2.—COMPARISON OF VARIOUS COOLANTS

Coolant	Flash Point ° F.	Coolant Temperature ° F. Theoretical	Coolant Temperature ° F. 20% Safety Factor	Cost of Initial Coolant
24% $CaCl_2$ brine	–	10.6	5.0	$ 850
32% Methanol	108	8.4	2.3	3,500
Stoddard solvent	100–110	5.6	−0.6	3,220
60% THFA (tetrahydrofurfurol)	167–176	3.6	−3.2	22,100
40% Ethanol	117	0.7	−7.2	9,500
Kerosene	100–165	−2.1	−10.5	2,300
45% Ethylene glycol	247	−7.4	−16.4	12,700

TABLE 3.—REFRIGERATION LOAD FOR A 30,000-TON UNIT

	Refrigeration Tonnage	Percentage of Total
Heat of polymerization	450.2	63.5
Heat of agitation	40.8	5.8
Heat of brine pumps	61.8	8.7
Heat gain through insulation	12.6	1.8
Sensible heat of charging ingredients	142.7	20.2
Total	708.1 Tons	100.0%

Fig. 5. Refrigeration area.

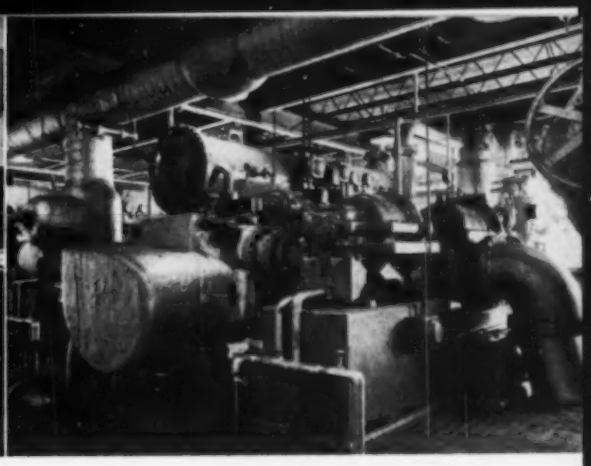

Fig. 6. Refrigeration machine.

TABLE 4.—STANDARD DEVIATIONS FOR BATCH AND CONTINUOUS PRODUCT PROPERTIES

Chemical Properties	Batch	Continuous
Volatile matter, %	0.121	0.118
Ash, %	0.227	0.098
Rosin acid, %	0.157	0.151
Soap, %	0.087	0.025
Styrene in polymer, %	1.96	0.15
Stabilizer, %	0.097	0.076
Physical Properties		
Raw viscosity, Mooney, *ML-4'* @ 212° F.	4.355	2.863
Compounded viscosity, *ML-4'* @ 212° F.	3.410	1.825
Tensile, 50' cure, lb./sq.in.	207	125
Elongation, 50' cure, %	19	23
300% Modulus, 25' cure, lb./sq.in.	47	28
300% Modulus, 50' cure, lb./sq.in.	70	37
300% Modulus, 100' cure, lb./sq.in.	64	46

TABLE 5.—STANDARD DEVIATIONS FOR BATCH AND CONTINUOUS PROCESS CONTROL

	Batch	Continuous
Reactor Mooney, *ML-4'* @ 212° F.	15.08	8.06
Reactor conversion, %	5.67	4.18
Reaction time, hr.	2.27	0.486

using 5° F. brine, process side-wall temperatures on the colder sections are below aqueous solution freezing points and a thin coating of ice must be assumed. Consequently heat-exchanger design at colder sections involves heat-flux calculations across only the process liquid film assuming a film Δt equivalent to the difference between the bulk temperature and the freezing point temperature. Figure 7 shows the two feedstock coolers used for batch charging. The small cooler on the right which is used only for monomers in batch charging handles the entire load in the continuous process.

A constant menace to a successful cold process is an excessively long reaction time and one of the accepted causes for retardation is dissolved oxygen. At the Port Neches plant water is vacuum-deaerated to < 0.1 p.p.m. oxygen at the water treatment plant in order to minimize corrosion. It became important to minimize any subsequent aeration while dissolving soap, activator, etc. Existing solution tank agitators caused absorption of as much as 10 p.p.m. of oxygen. By modifying agitation to eliminate vortex formation this was reduced to 2 p.p.m.

The influence of oxygen in retarding reaction also necessitates reactor evacuation before each batch in the case of the batch process. This procedure is of course eliminated in the case of the continuous process because of the constant and automatic purging inherent with the continuous flow. In fact, this and additional labor savings by eliminating batch charging and blowdown operations are sufficient to reduce labor requirements by one operator per shift per 30,000-ton unit.

The chief advantage of the continuous process is increased capacity. This is due first to the complete filling of reactors. In the batch system they are filled to only about 90% of the total to avoid overfilling and overpressuring. Secondly, increased capacity is gained from elimination of downtime necessary in the batch system for charging and discharging the reactor. This amounts to more than an hour per batch. A third reason for increased capacity is the additional polymerization volume gained by the relatively simple addition of the displacement tubes. These factors total up to a theoretical capacity increase of 15-20%, but this is based on an equivalent reaction time. Actually, when continuous cold rubber was put on stream in October, 1949, continuous reaction rates were so much slower that only a 4%-capacity increase was realized. With greater know-how, derived from experience, and further development of improved recipes and techniques, the full theoretical capacity increase has been attained.

Another important advantage of continuous cold rubber over batch is the improved uniformity of process control and product quality.

Table 4 shows a typical set of standard deviations of chemical and physical properties of the batch and continuous processes on the same recipe production.

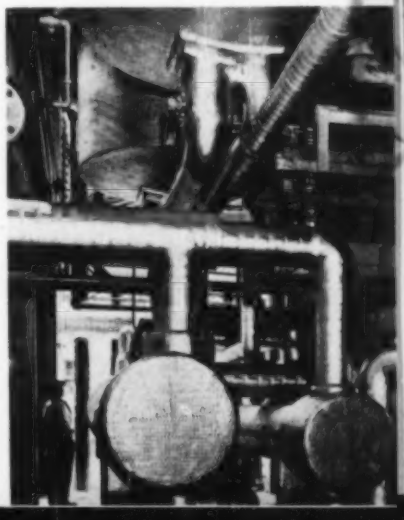

Fig. 7. Feedstock coolers. ►

Table 5 shows a comparison of batch and continuous process control uniformity.

A further advantage of the continuous cold rubber process which has not yet been fully exploited is the possible use of waste heat exchange on the feedstock stream and finished latex. Preliminary tests show that such units may be practical to the extent of 50 to 75% heat regeneration and of course will show more promise the lower the polymerization temperatures. The unit would show its greatest advantage on future expansions where it will be possible to reduce refrigeration equipment requirements by 70 to 100 tons for the plant size described in this report.

The advantages of the continuous process for cold rubber may be summarized as follows:

1. Increased capacity
2. Improved product uniformity
3. Improved process control uniformity
4. Reduced operating labor
5. Reduced process and refrigeration equipment requirements
6. Reduced surges on utilities
7. Possible reduced utility requirements by waste heat exchange

These advantages have benefited more than 65,000,000 lb. of cold rubber produced since the unit first went into operation.

Discussion

Bronson Harris (The Dow Chemical Co., Midland, Mich.): Three questions—(1) What over-all heat-transfer coefficient did you obtain through the walls of your reactors? (2) Would you describe more completely the jacket agitation nozzles? (3) Against what pressures do your feed pumps have to pump and what type of pumps do you use?

Marvin W. Larson (B. F. Goodrich Chemical Co., Cleveland, Ohio): By the first question I presume you mean the coefficients in the reactor jackets. We got over-all coefficients in the neighborhood of from 25 to 30 with inside films of about 35 to 40.

On the second question—the jacket agitation nozzles take the place of spiral agitators and they are nothing more than water ejectors which keep the stream of water or brine circulating around the jacket peripherally by taking energy from the incoming coolant and transferring it to the bulk of the coolant in the jacket, thereby increasing jacket velocities and jacket film coefficients.

The answer to your third question is that the pumps are turbine-type pumps; they operate in the neighborhood of 110 to 120 lb./(sq.in.)(g.) discharge pressure.

J. H. Wardwell (Dow Chemical Co., Midland, Mich.): What type of gasket did you standardize on for your glass-enameled flanges on your equipment?

M. W. Larson: I think we have standardized on a lead-sheathed asbestos gasket for glass-lined vessels.

(Presented at Forty-third Annual Meeting, Columbus, Ohio.)

LETTER TO THE EDITOR

REACTORS IN SERIES

SIR:

It is interesting to relate the graphical analysis by Jones (*3*) with that part of the paper by Eldridge and Piret (*2*) dealing with graphical analysis.

Equation (*7*) of Eldridge and Piret may be written $a_{n-1} = a_n - \theta_n (da/dt)_n$, in which a is the concentration of the reactant of interest, n refers to the number of the reactor, $-(da/dt)_n$ is the time-rate at which the reactant is being used up in the nth reactor (constant in any single reactor), θ_n is the nominal holding time, or the volume of the reactor divided by the volumetric feed rate: V_n/F_n. A steady-state continuous process is assumed. The graphical solution presented by Eldridge and Piret uses their Equation (*7*) with the additional limitation that θ_n is the same for all the reactors in series and that the subscript may be dropped, giving the eqution $a_{n-1} = a_n - \theta(da/dt)_n$. Then, if the constant value of θ is known, and if a series of values of da/dt corresponding to values of a has been obtained by graphical differentiation of experimental values of a vs. time t in a batch run, it is plain that the substitution of these numerical values in the equation enables the plotting of a_{n-1} vs. a_n.

Also, since the numerical value of a_n for one reactor is a_{n-1} for the next, the diagonal $a_n = a_{n-1}$ is drawn. Then, starting with the point on the curve whose ordinate is $a_{n-1} = a_o =$ the concentration of a in the feed to the first reactor, vertical and horizontal lines are drawn stepwise between the curve and the diagonal until the desired concentration in the product is reached or passed. The number of points thus touched on the diagonal is the number of reactors required. This is the method of Eldridge and Piret, but they applied it only to cases in which da/dt could be expressed analytically as a function of a velocity constant and of a, thus requiring a knowledge of the order of reaction and its velocity constant. The fact that the equation could be used with primary experimental data on a batch run was realized by the writer soon after hearing the Eldridge and Piret paper presented in December, 1949, and was using it in classroom instruction early in 1950.

Rearranging Equation (*7*) of Eldridge and Piret gives $(da/dt)_n = (1/\theta)_n (a_n - a_{n-1})$. Plotting da/dt as ordinate vs. corresponding values of a, a curve may be drawn. Then, starting on the base-line ($da/dt = 0$) at $a = a_o$ = concentration of reactant in feed to first reactor, a straight line with slope $= 1/\theta_1$ may be drawn. The intersection of this line with the curve gives the value of a_1, the constant concentration in the first reactor. That this is the required point can be seen immediately from the geometry of the diagram, in which slope $= 1/\theta_n = (da/dt)_n/(a_n - a_{n-1})$. Dropping vertically from this point to the base-line ($da/dt = 0$) gives the starting point for the straight line for the next reactor, of slope $1/\theta_2$, and so on. This is the method of Jones (*3*), and it has the advantage over the method of Eldridge and Piret in that it can handle graphically cases of reactors in series in which θ can vary from one reactor to the next. In other words, the reactors may all have different volumetric capacities with constant volumetric flow rate. For ordinary cases, the two methods will give identical results from the same primary data, and there is little choice between them. In many cases, as pointed out by Denbigh (*1*), use of tank reactors of different sizes in series provides the most economical arrangement.

It should be emphasized that the use of differentiated experimental batch data in the calculation of reactors in series by either of the two graphical methods will give completely erroneous results in certain cases of complex reactions. Therefore the designer must know the nature of the reactions involved. The cases to which the graphical methods do not apply are coded by Jones (*3*) and are tabulated and discussed in some detail by Eldridge and Piret (*2*). In such cases no short-cut method seems available, and the tedious stepwise calculation from one reactor to the next is the safe procedure.

New York, N. Y.

Albert B. Newman

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1. Denbigh, K. G., *Trans. Faraday Soc.*, **40**, 352 (1944).
2. Eldridge, J. W., and Piret, E. L., *Chem. Eng. Progress*, **46**, 290 (1950).
3. Jones, R. W., *Chem. Eng. Progress*, **47**, 46 (1951).

• NEWS SECTION •

LOCAL SYMPOSIA AT BOSTON AND PITTSBURGH

TWO Technical Symposia by A.I.Ch.E. local sections were held last month, one at Boston, the other at Pittsburgh, this latter conference the work of a combination of local sections at Akron, Columbus, Cleveland, Ohio Valley, Toledo and Pittsburgh.

Boston, with a five-speaker meeting and dinner, investigated the place in management for chemical engineers, while Pittsburgh held an all-day conference on ion exchange.

Local groups of the A.I.Ch.E. are finding in such symposia an answer to their specialized technical requirements, and many have planned all-day technical meetings with well-known speakers. Added advantages that local section officers are finding from sponsoring and holding such meetings were brought out in several interviews on the subject by the editor, namely a better spirit among local section members and a local group with better cohesiveness and purpose.

At Pittsburgh, the symposia on, "The Application of Ion Exchange," was held with the local section acting as host. R. S. Rhodes of the Koppers Co., was general chairman and presided over the eight papers which were given during the day. G. F. D'Alelio, vice-president and director of research, Koppers Co., Inc., opened the meeting with a discussion on the industrial importance of ion exchange as a new tool. He commented upon the part played by chemical engineers in taking ion-exchange ideas developed by scientists and transferring them to full-scale, plant-sized equipment. Speaking of the part the chemical engineer has played in this, he said, "Industry looks to you to engineer the application of these (ion-exchange) materials to their needs. You have gone far beyond their use in water treatments . . . . used it as a tool in the separation and identification of the fission-produced radio-isotopes. . . . . applied it to the concentration, separation, and recovery of copper, silver, chromium, molybdenum, vanadium, platinum, and gold from industrial wastes. . . . . You have used ion exchange in sugar refining, in pectin manufacture, in tartaric acid manufacture, in alkaloid recovery, Vitamin B recovery, in milk processing, in the separation of amino acids from protein hydrolyzate, and in many, many other interesting and profitable fields."

In the first technical paper by O. M. Elliott, water conditioning engineer, Sun Oil Co., ion-exchange experiments were traced back to Sir Francis Bacon, and Mr. Elliott quoted from a technical paper by Bacon, describing trials made in removing salt from sea water by passing the water through beds of soil.

After tracing various historical episodes involved in ion exchange, Mr. Elliott finally gave credit for the quantitative recognition of ion exchange to Prof. J. Thomas Way, and a scientific farmer, H. S. Thompson. Professor Way, a consulting chemist for the Royal Agricultural Society of England, began his investigations into ion exchange while investigating the use of chemical fertilizers. Mr. Elliott said, "Farmer Thompson was impressed by the fact that 'manures such as potassium and ammonia' are taken up by the soil, strongly held despite the leaching action of rain, and yet are available to fertilize the growing plants. After many practical observations and chemical tests, farmer Thompson informed Professor Way that . . . .

> 'when solutions of salts of ammonia, potash, magnesia and so forth were made to filter slowly through a bed of dry soil five or six inches deep, arranged in a flower pot or other suitable vessel, it was observed that the liquid which ran through no longer contained any of the ammonia or other salt employed.'

According to Mr. Elliott the real connective in ion-exchange theory, came with the acceptance of ionic association.

The second paper by Robert Kunin, Rohm & Haas Co., described recent developments in the industrial application of ion exchange and stressed the relatively new monobed technique developed by his organization. (Chemical Engineering Progress, Vol. 46, June, 1950, p. 18.)

In the discussion on, "Purification of Organic Chemicals by Ion Exchange," the authors listed ten organic chemicals now being treated by ion-exchange processes among which were various sugars, alcohols, formalin, acids, pectin, blood, etc.

The authors described how crude methanol, made synthetically from carbon dioxide and hydrogen, is separated by ion exchange from the excessive amounts of amines and ammonia which are produced during starting up or shutting-down operations. They said in part, ". . . . passage of the crude methanol through a cation exchange resin operating on the hydrogen cycle completely removes the amines and ammonia. At the start of a converter cycle, amines and ammonia are present in concentrations up to 400 p.p.m. and they are present at an average concentration of 8 to 10 p.p.m. during the remainder of the cycle. This quantity of 8 to 10 p.p.m. is sufficiently low that subsequent normal treatment produces a satisfactory methanol. However, it is difficult in plant operation to predict when it will be necessary to shut down a converter and it is during this shutdown and consequent starting periods that a highly contaminated product is obtained. Since ion exchange adds no contaminants and does remove contaminants which may be present only in low quantities, it was found in actual plant operation advantageous to pass all the methanol produced through the ion exchange equipment."

They indicated further that such treatment results in an efficient which had no more than one part per million of ammonia or amine concentration after passing through the cation exchanger. They stated that sulfonated styrene cation resins were the most satisfactory to use in this application.

Another example discussed by the authors concerned sulfuric acid, used as a catalyst in the hydrolysis of ethylene or ethylene glycol, and its removal from the ethylene glycol mixture by a weakly basic anion exchange resin. The sulfuric acid content was reduced from 0.15% to 0% during the operation.

The authors also described the removal of formic acid from formaldehyde, reduction of color from organic chemicals, removal of dyes from organic solvents, and the removal of salt from blood serum.

(Continued on next page)

In discussing the use of ion exchange in the dairy industry, E. F. Almy quoted experiments in which an ion-exchange material was used to reduce the calcium content of milk 45% through exchange with sodium ions and with no effect on the phosphorous content.

He also told about a process for producing lactose from whey. In this process, according to Dr. Almy, ". . . . the protein was first removed by acid coagulation, then the deproteinized whey was passed through suitable pairs of ion-exchangers. The demineralized effluent was then concentrated and spray-dried. In order to obtain the desired acidity for deproteinizing the whey, part of a batch was first treated by a cation-exchange resin in the hydrogen cycle. This resulted in an effluent with a pH of 1.5-2.0 by removing all the cations and giving off hydrogen ions to the effluent. This very acid whey was blended with untreated whey to give a final mixture of pH 4.6-4.8 which is the approximate isoelectric point of the protein present. This acid whey was then heated to about 90° C. to coagulate the protein, filtered, and then subjected to the ion-exchange treatment at room temperature. By this process practically all the lactose present in the whey is recovered, in contrast to the 50-75% yield usually obtained by crystallizing procedures."

MANAGEMENT SYMPOSIUM

Editor's Note: *The following report on the Boston symposium was written at the editor's request by Laurent Michel, of Godfrey L. Cabot, Inc., and E. L. Cherenson, of Artisan Metal Products, Inc.*

THE Engineer in Management was the topic for the Ichthyologists (Boston Section A.I.Ch.E.) First Technical Symposium held at Boston's Hotel Lenox on April 12 and 220 registered for the event. Speakers were Earl P. Stevenson, President, Arthur D. Little, Inc., Cambridge, Massachusetts; Robert M. Coquillette, Manager, Rubber Specialties Division, Dewey and Almy Chemical Company, Cambridge, Massachusetts; William F. Ryan, Engineering Manager and Vice President, Stone and Webster Engineering Corporation, Boston, Massachusetts; John L. Gillis, General Manager, Organic Chemicals Division, Vice President, Monsanto Chemical Company, St. Louis, Missouri, and Thomas K. Sherwood, Dean of Engineering, M.I.T., Cambridge, Mass., who delivered the dinner address.

The speakers, each representing different areas of industrial management, were asked to discuss the characteristics and training which will offer the young engineer entering an organization the greatest assurance of his moving into a position of managerial responsibility.

The steps which their organizations are taking towards the training and development of young engineers for ultimate positions in management were also discussed.

Criteria which a young engineer should have in entering the field of research and development were listed by Mr. Stevenson. These are: ability to get along with people and to make a favorable impression, broad technical interests, initiative, self-assurance, qualities of leadership, energy and aggressiveness to undertake responsibility, ingeniousness and scientific curiosity and ability to express one's thoughts. Further criteria, some of which can be developed, were according to Mr. Stevenson good judgment, a technical knowledge sufficient to gain the respect of one's associates, a proper sense of values, ambition, a willingness to work harder than the average, and an observant and tolerant attitude.

Discussing steps taken by Arthur D. Little, Inc., to develop managers, Mr. Stevenson stated that the company policy was to study the young men and give them as much responsibility as they could shoulder. Other methods include proper incentives, encouraging participation in technical societies and preparation of papers, planning and program meeting, introduction to other parts of the organization, and close contact with superiors.

A pace consistent with the situation was recommended, since the speaker recognized that few people in any organization are capable or destined to become managers and many a good research worker or engineer has been sacrificed by a poorly advised move into management.

In the field of production, Mr. R. M. Coquillette stressed the need for physical energy and drive. An abounding vitality which can diffuse to others acts as a stimulant to increase output. Also important are a genuine interest in people and problems, an appreciation of what it means to work with the hands and some feeling for the dignity of man.

Foremost, however, in production management is the cooperative effort, since there is no place for the prima donna.

Mr. Coquillette stressed the fact that the engineer with managerial tendencies can move smoothly within a group of other engineers, mechanics, operators, and salesmen. What becomes important is not technical training, but the qualities of judgment, the ability to determine what the problems are and the ability to think quickly and universally.

At Dewey & Almy, development of a Production Manager is carried out through a three-phase process. In the first phase, the new man is company indoctrinated. The program is designed to maintain a high level of interest and an important part of it is close contact with other company members so that a feeling of team work is developed. Acceptance of responsibility is also stressed. On-the-job training constitutes the second phase of the program. To develop responsibility, the job must be chosen so that easy answers are not available, yet it must be such that mistakes will not render training too expensive. In the third phase, the candidate has reached the point where with the acceptance of responsibility, the particular job can be kept under control with continued guidance in distinguishing the relative importance of problems.

Mr. W. F. Ryan approached the subject from the field of engineering, stating that there was undue emphasis in the minds of many young engineers on the importance of management as a goal towards which an engineering career should be shaped. Equal energy devoted to achieving excellence in engineering may be equally rewarding, financially, and more so, from a professional point of view, he indicated.

Mr. Ryan went on to point out, however, that engineering is the group most heavily represented in the top flight management of American industry. Thus, an engineering degree is a good start towards a management post. The next step, said Mr. Ryan, is to advance oneself intensively in technical aspects. This type of progress requires homework, extensive reading and study, membership in technical societies and other similar activities.

Mr. John L. Gillis, who discussed the field of sales, commented on the lack of engineers in chemical sales. He pointed out that of the seven heads of major sales organizations in Monsanto, only one has an engineering degree and similar situations exist in other companies.

The reason for this may be, he said, that most engineers have gone into other fields. In his opinion, purely technical professional work decreases the engineer's chances of success in sales. Other possible reasons for this shortage are the engineering schools' neglect, until recently, of the nontechnical aspects of training, a demand for engineering talent which has exceeded the supply, and the possibility that engineers as a group are more interested in things than in people.

Mr. Gillis, however, predicted that within ten years, the percentage of engineers in top sales management will have increased. Intelligence, good ap-

(*Continued on page 42*)

CORROSION COURSE IN JUNE AT M.I.T.

Leading industrial authorities will join members of the M.I.T. faculty to present a one-week intensive course in Corrosion at the Massachusetts Institute of Technology from June 18 to 23, 1951, according to Prof. Walter H. Gale, director of the M.I.T. summer session. Principal purpose of the week-long event, Dr. Gale reports, will be to bring new information about corrosion control within the reach of men in industry. One of a series of special activities to be held at M.I.T. during the coming summer, the course will be under the direction of Prof. H. H. Uhlig, in charge of the Institute's Corrosion Laboratory.

The course will cover the characteristics and mechanisms of corrosion and corrosion control. On the schedule are discussions of the design of equipment, chemical treatment of the environment, cathodic protection, and selection of coatings and alloys economically feasible for reducing corrosion losses.

The one-week program, according to Dr. Uhlig, is designed to meet needs of research directors and plant engineers who wish to review recent trends and developments.

The following lectures are scheduled:

Fundamentals of Corrosion Reactions and Control, H. H. Uhlig, associate professor of Metallurgy, M.I.T., and Carl Wagner, visiting professor of metallurgy.

Metals and Alloys: Properties, and a Guide to their Proper Selection, W. Z. Friend, International Nickel Co., Inc.

Cathodic Protection: Theory and Measurements, J. M. Pearson, Sun Oil Co.; *Practice and Economics*, L. P. Sudrabin, Electro Rustproofing Corp.

Metallic and Organic Coatings: Selection, Application, and Behavior, R. M. Burns, Bell Telephone Laboratories.

Treatment of Environment, Norman Hackerman, department of chemistry, University of Texas.

Design of Equipment from a Corrosion Standpoint, R. B. Mears, Carnegie-Illinois Steel Corp.

Principles and Practices of Corrosion Testing, F. L. Laque, International Nickel Co., Inc.

DACRON, NEW TRADE-MARK DU PONT FIBER

Dacron is the new trade-mark which has been adopted by the Du Pont Co. for its polyester fiber, originally known by the laboratory designation of Fiber V and later given the trade-mark Amilar ("C.E.P." p. 29, March, 1951.)

The Dacron trade-mark was substituted for the Amilar mark when the company received advice of its possible confusion with an unrecorded commercial name.

GAS PLANT USES SEA WATER COOLING

A new gas conversion plant built recently by Long Island Lighting Co. is using a new method of tapping sea water as a cooling medium. The plant converts natural gas into a gas closely approximating water gas by a reforming metal. Natural gas has become available from the Southwest through Transcontinental Pipe Line Co.

The gas is reformed by a catalytic cracking process utilizing specially designed furnaces developed by Surface Combustion Co. Plant capacity is approximately 35,000,000 cu.ft. of natural gas/day. After cracking, the reformed gas is enriched and stored.

Cooling water problems are associated with both the reforming process and with gas compression for distribution. In both instances it is necessary to employ recirculatory, closed water systems because ground water is not available in sufficient volume for a once-through system, and sea water would create a serious salt corrosion problem if used directly.

Reformed gas passes through a closed scrubber tower and the water picks up a large quantity of heat as well as residual impurities.

The two basic cooling jobs are to cool the recirculating scrubbing liquor and the fresh water that is circulated in the jackets of the gas compressors and their prime movers.

The equipment used for cooling all recirculated fresh water consists of built-up batteries of cast iron cooling sections over which salt water from Hempstead Harbor is sprayed. The cooling sections, are made of highest grade cast iron, and have high resistance to salt water corrosion. According to The National Radiator Co., who designed and supplied the cooling section, they have proved economical in both first cost and maintenance.

The coolers, designed for a minimum of evaporative cooling in order to avoid salt incrustation, are placed close together and are surrounded by Transite walls. The walls prevent salt mist from being blown over other corrodable structures or equipment made of carbon steel.

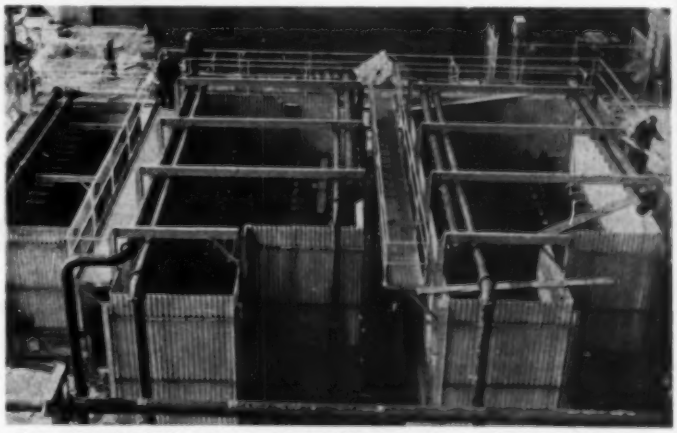
The scrubbing liquor cooler is arranged in three parallel banks, each serving scrubbers for one of three Surface Combustion cracking furnaces. The three banks are interconnected in order to provide maximum operating flexibility. There are 418 sections in each bank which has two rows of sections in series, each row consisting of 11 parallel stacks, 19 sections high.

The combined cooler with 1254 sections was designed to cool 1800 gal./min. of scrubbing liquor from 140° F. to 95° F. when supplied with 2325 gal./min. of sea water at 70° F.

The cooling of water in the compressor and engine jacket system is similar to that for scrubbing liquor. Jacket water is circulated through closed systems and cooled by means of once-through salt water. Compressor jacket water must be kept within a temperature range of 113 to 90° F. in summer and engine jacket water must be kept within a temperature range of 162 to 150° F.

There are five compressors. Two, which are driven by 2000-hp. natural gas engines, are each provided with a cooler consisting of 256 sections arranged in 16 parallel stacks, 16 sections high. They cool 550 gal./min. of jacket

(*Continued on page* 42)



Long Island Lighting Co. plant for cooling compressor and engine jacket water. The compartment at left is for motor-driven compressors, and the other two compartments are for the two gas-engine-driven compressor units. Transite walls minimize salt water corrosion of surrounding equipment.

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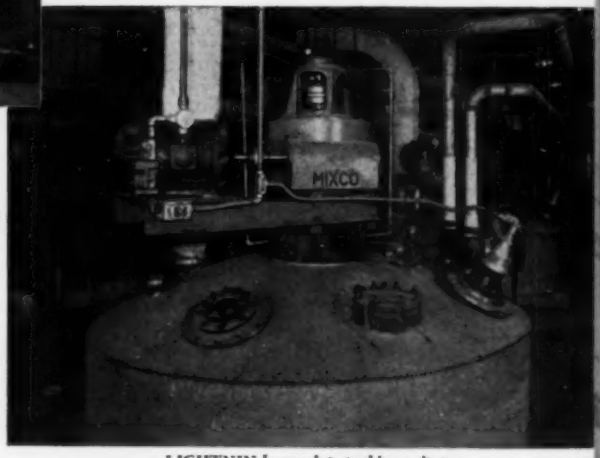

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- ☐ DH-50 Laboratory Mixers
- ☐ B-36 Condensed Catalog showing complete line
- ☐ B-75 Portable Mixers (Electric and Air Driven)

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EQUIPMENT

1 • HEAT EXCHANGER. For solvent recovery, the Modine Manufacturing Co. announces a plate-type heat exchanger which has interlocked-channel-type fins with special embossings or interrupted surfaces. Provides 250-300 sq.ft. of surface area/cu.ft. Designed for assembly into blocks to provide for expansion of capacity.

4 • MECHANICAL SEAL. For service on rotating shafts such as centrifugal pumps, turbines, agitators, etc., Crane Packing Co. announces an improved mechanical seal for use under severe temperature and corrosive conditions. The new type seal incorporates a flexible ring molded from Teflon.

5 • DOWTHERM UNITS. A standard line of electrically heated Dowtherm heat-transfer units complete with instruments, piping, insulation, etc., is a development of the Struthers Wells Corp. Capacities range from 100,000 to 500,000 B.t.u./hr. at temperatures up to 750° F. Entire unit is base-mounted for immediate factory installation. Features a special heating element designed to eliminate thermal breakdown or coking troubles. Bulletin available.

7 • GRATING MONOCHROMATOR. Baird Associates, Inc., announces a 1-μ grating monochromator with a spectral range extending from the ultra-violet (2,000 A) into the infrared to 6μ, without interchanging optical components.

8 • CHEMICAL PUMP. Nagle Pumps, Inc. has a new vertical and horizontal shaft centrifugal pump. Available with impeller and housing of various alloys for handling corrosive liquids, double stuffing-box, split bearings, low-entrance losses for operation under low n.p.s.h. conditions. Efficiency charts and other data available.

9 • VALVE ACTUATOR. For operation of gate valves, plug valves, dampers, diaphragm valves, butterfly valves and sluice gates, a valve actuator of Ledeen Manufacturing Co. Pressure fluid operated, since valves are basically cylinders equipped with valves and controls. May use pressure fluid as low as 15 lbs./sq.in. or as high as 750 lbs./sq.in. Feed controls, on-and-off service, positioning control, and emergency hand pumps are all available with the actuator.

10 • WORM AND GEAR VALVE. Homestead Valve Manufacturing Co. has added worm-and-gear-operated valves to its line of lubricated plug valves. Come in 8-in., 10-in. and 12-in. sizes. Port area is equivalent to 100% of standard pipe. Features such as venturi-types, full-port cast-steel types, etc., are available.

11 • LIQUID LEVEL CONTROLLER. For external mounting on vessels, kettles, etc., where it is desired that the liquid level control be isolated without shutting down the main systems when repairs or adjustments are necessary, Black, Sivalls & Bryson, Inc., has a new type displacement unit. Utilizes torsion tube assembly for transmitting level changes, no packing glands.

12 • VACUUM GAUGE. Inexpensive vacuum gauge for industrial high-vacuum equipment which covers a range of a few microns to 1 mm. of mercury, is available from Distillation Products Industries. Known as the thermocouple gauge, it is available with from two to six stations reading on a single meter. Suited for checking pumping conditions, the principle of the gauge based on the e.m.f. developed by a thermocouple in which the temperature differential depends on heat loss by gas conduction, which in turn depends on gas pressure. Complete details available.

14 • EMULSIFIER LIQUID ROSIN SIZE. American Cyanamid Co. has an automatic emulsifier for liquid rosin size. The emulsifier is a compact, pre-assembled unit which is connected to tank car rosin-size storage facilities and has a single discharge line to one dilute emulsion tank. Dimensions of the unit are about 5 ft. wide, 4 ft. deep by 6 ft. high. Machine delivers a fine particle-size emulsion and the solids content of the emulsion will be accurate to ±0.1%. Emulsification is done by an emulsifying valve and venturi jet. Unit is electrically interlocked and can handle standard and interchangeable parts.

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CHEMICALS

20 • *3,3'-IMINOBISPROPYLAMINE.* Car-lot quantities of this compound are available from the American Cyanamid Co. Strongly basic amine, colorless, high-boiling, completely miscible at room temperature with water and most common organic solvents. Useful in the synthesis of ion-exchange resins, has potentialities as intermediate for surface-active agents, pharmaceuticals and dyestuffs. Bulletin covering physical and chemical properties is available.

21 • *TRICHLOROBENZENE.* Pennsylvania Salt Manufacturing Co. offers pilot plant amounts of trichlorobenzene. Clear, colorless liquid with a 1,2,4 isomer predominating. Major ingredient in compounded transformer oils, solvent for oils, fats, waxes, etc. New product bulletin describing chemical and physical properties available.

22 • *AMMONIUM BICARBONATE.* Chemical Manufacturing Co., Inc., is offering ammonium bicarbonate, a product of Imperial Chemical Industries, Ltd. Available in 244-lb. drums, immediate delivery, for use in making baking powder, pharmaceuticals, rubber manufacturers, etc. Technical data sheet also available.

23 • *NEW MATERIALS.* Unnamed as yet, Great Lakes Carbon Corp. offers new products made of perlite. A report is available which gives physical properties and suggested uses for these materials which are dry, white powders having a chemical composition high in silicates and aluminum oxide, with a small percentage of other elements. Inorganic, insoluble in water and most acids. Specific heat is 0.20 B.t.u.'s/lb./° F. K factors as low as 0.22 B.t.u. Have good use as insulators, drilling and cementing of oil wells, fire retardance, reduction of gloss, adding bulk, etc. Bulletin gives complete details.

24 • *SILICON BINDER.* For making a strong bond between silicone rubber, General Electric Co. has developed a new primer. Silicone rubber can be bonded to any other surface such as glass, aluminum, steel, and tin. Sheer strength measurements of bonds on steel are approximately 700 lbs./sq.in. Applied by dipping, draining, spray, or brushing; requires only an air-dry between application and molding.

25 • *AMINOPYRIDINES.* Reilly Tar & Chemical Corp. with two new products—2-amino-4,6-dimethylpyridine and 2,2'-dipyridylamine ($C_{10}H_9N_3$). Data sheets give the physical constants, etc., and are available from the company. This is part of the Reilly development of pyridines which offers 2-aminopyridine also used in synthesis of antihistamines.

26 • *SULFONES.* Merrimac division of Monsanto Chemical Co. has added three sulfones to its line of commercially available chemicals. They are bis-(p-chlorophenyl) sulfone, bis-(3-amino-4-hydroxyphenyl) sulfone, and bis-(4-chloro-3-nitrophenyl) sulfone. For use in the dyestuff, organic synthesis, biocide, etc., fields. Experimental quantities and data sheets giving physical properties of the new products available.

27 • *VINYL PLASTIC COATING.* Control of corrosion on exteriors of steel, concrete, brick, formed block and plywood, and as a tank lining are covered by Casey & Case Coating Co. in its description of a series of vinyl coatings. Specific properties, chemical resistance are charted. Coatings are of thermoplastic resin base, inert and can be used in constant contact with food products. Given are methods of application, surface preparation, price list, etc.

28 • *ANTI-FOAM.* For defoaming a wide range of compounds, General Electric Co. has developed a silicone anti-foam agent which works in concentrations as low as 75-100 p.p.m. in a variety of products such as high-polymer rubber dispersions. The anti-foam is a white, colorless liquid which may be dissolved in petroleum naphtha, tulol, xylol, chlorinated aliphatics, etc.

29 • *SANTOCEL.* The use of Santocel, Monsanto Chemical Co.'s aerogel, in formulation of lubricating greases is described in a data sheet. Covers high oil absorption powers and is particularly effective as a thickening agent in nonpolar liquids. Particularly interesting in thickening an oil to a grease. Physical and chemical properties of this SiO_2 product are given.

30 • *REMOVING SULFIDES FROM WATER.* Resinous products division

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of Rohm & Haas Co. announces via a bulletin a strongly basic Amberlite IRA-410 which will remove sulfides as well as sulfates, bicarbonates, and fluorides from water supplies. Uses equipment similar to standard water softener. Full details given in a technical bulletin.

BULLETINS

35 • *PRODUCING SO_2.* The Dorr Co. Fluosolids system for roasting of sulfides. Bulletin, intended for sulfuric acid manufacturers and other users of sulfur dioxide, explains how fluidization principle is extended to roasting pyrite and pyrrhotite. One important advantage of the fluidization system is a higher SO_2 content of gas. Averages 14 to 15% SO_2, for 48% pyrite. Continuous system, calcined material overflows and passes out of the reactor. Flow sheets are shown, operating results, analysis, advantages, application, etc.

36 • *PROCESS EQUIPMENT.* Pamphlet describing products manufactured by the Cleveland Mixer Co. Covers agitators, turbines, reaction vessels, blenders, flocculators, mixers, heaters, etc.

37 • *GAS VALVE.* An improved plate-type gas valve of the S. P. Kinney Engineers, Inc., is described in a leaflet. Valve sizes from 36 in. to 108 in. Primarily for use in blast furnaces and in steel mills. Lists ten advantages, gives dimensions, weights, etc.

38 • *CORROSION-PROOF LININGS.* For protecting concrete or steel against corrosive liquids, the experience of the Atlas Mineral Products Co. with various sheet linings, solution and dispersion linings, bricks, sheathings, and miscellaneous materials, is listed in a 4-page pamphlet. Types of plastics used, physical properties, resistance to corrosive solutions, etc., are all described.

39 • *COOLING TOWERS.* Description of Binks Manufacturing Co. blower-type cooling towers. Two models, . single fan model with capacities ranging from 3 to 30 tons of refrigeration, and a two double-inlet squirrel-cage blower tower with 32-60 tons of refrigeration. Capacities of the single fan model from 3 gals./min. to 90, double from 96 to 180. Liquid-sprayed with jet nozzles, mist removed with redwood drift eliminators. Data sheets included.

40 • *ION-EXCHANGE EQUIPMENT.* Water conditioning equipment of Illinois Water Treatment Co. Covers softeners, hydrogen zeolite, deionizers, and mixed-bed deionizers. Includes specifications on units available for flow rates up to 1000 gals./hr. Shows chemical composition of a standard water after passing through the various operations. Principles explained, equipment shown, etc.

41 • *SAND FILTER-CLARIFIERS.* Hardinge Co., Inc., describes line of sand filter-clarifiers. Used for processes where a crystal-clear filtrate is desired. Principle used is downward filtration through a sand bed with a spiral scraper which takes a cut from the top of the sand bed when filter rate decreases. Bulletin details descriptions, capacities, operation principles, advantage, details of filter bed, flow rates, etc.

42 • *LIQUID PROCESSING.* Bulletin describes, specifies construction details of equipment manufactured by the Alsop Engineering Corp. for handling liquids. Mixers, filters, tanks, pumps, disc filters, agitators. Photographs of actual equipment as installed.

43 • *VACUUM GREASES AND OILS.* For high vacuum work, James G. Biddle Co. bulletin on a dozen oils, greases and waxes for diffusion pumps, stop cocks, ground joints, permanent joints, etc., in vacuum systems. Recommended applications, vapor pressures of the greases at room temperature, safe maximum temperatures for uses, prices, and industries that now use these products are all part of publication.

44 • *PROCESSING MACHINERY AND EQUIPMENT.* A 56-page Patterson Foundry & Machine Co. catalog of all processing equipment. Includes mixing equipment of all types, including paste mixers, simple agitators, horizontal mixers, etc. Dowtherm processing kettles and systems, plasticizing pans, kettles, autoclaves, nitrators, etc., grinding equipment, ball mills, tube mills, dryers, classifying equipment, etc.

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45 • INDUSTRIAL CONTROLS. For temperature, flow, liquid level, and humidity control, Minneapolis-Honeywell Regulator Co. in a 60-page catalog presents more than 100 different models of nonindicating electric, electronic, and pneumatic controllers. Control principles for each controller is given plus a cut-away view with important parts labeled, specifications, ranges, etc.

46 • WATER FILTERS. A self-cleaning water filter by the Sparkler Manufacturing Co. for use in municipal, industrial, and other commercial applications. Uses precoat principle. Models vary from 15 to 300 sq. ft. of filtering area.

47 • DUST CONTROL. A bag-type dust suppressor for dust fumes and smoke, is a newly described product of the Whiting Corp. Unit has been approved by the Los Angeles Smog Control Board. Gases are cooled by sprays of water prior to entering into the baghouse.

49 • RESIN PUMP AND HEAT EXCHANGERS. Cast resin pumps and Karbate heat exchangers are featured in a leaflet of the Nukem Products Corp. Used for acid and alkali conditions, two pumps are available—one delivering 60 gals./min. at a 20-ft. head, the other 95 gals./min. at a 20-ft. head. The Karbate exchanger units are shown equipped with the plastic pumps for a completely corrosion-resistant pumping and heat-exchanging unit. Six different heat exchangers are listed.

50 • STATISTICS AS A TOOL. Experimetrics, Inc., a consulting service specializing in the use of a statistical analysis, has issued a bulletin explaining the service and showing how statistics can help to solve experimental problems of the chemical field. Correlation analysis, quality controls and designed experiments are all covered.

51 • HYDRO-TREATOR. For water softening, color or turbidity removal from municipal or industrial water supplies, the advantages of the Dorrco Hydro-Treator is described in a new color illustrated booklet of the Dorr Co. The hydro-treator is a high-rate, sludge-blanket unit. Filtration, clarification, and sludge collection and thickening, are accomplished in three separate zones. Available in standard sizes from 10 ft. to 30 ft. in 2-ft. steps and 30 ft. to 100 ft. in 5-ft. steps. Two types are offered which are fully described in this carefully prepared manual. Gives fields of application, advantages, capacity ratings using alum and alum plus activated silica, chemical dosage, operating data, chemical analyses, description of unit plus specifications, etc.

52 • BIN VIBRATOR. A description of air vibrators made by The Cleveland Vibrator Co. for loosening up hoppers, bins, chutes, batch mixers, etc. Prevents plugging, arching, and sticking. For use on powdered or granular materials. Air-actuated, fits on outside of hopper or bin over a reinforcing plate.

53 • NOZZLES, WELDING NECKS AND FLANGES. For the engineer concerned with pressure vessel work, this huge manual of the Taylor Forge & Pipe Works is offered. Enormous amount of material in addition to the descriptions and specifications of the Taylor line of nozzles, welding necks, and large diameter flanges. Seventy-two pages plus a 42-page bulletin on modern flange design. All details, specifications, proper use, etc., of these materials are covered in the book. Manufacturer will limit it to those having an interest in pressure vessel work.

54 • HYDROGEN ZEOLITES. An exhaustive explanation of zeolites with special emphasis on the use of hydrogen zeolites, a new Cochrane Corp. bulletin. History of the process, field of application of hydrogen zeolite data on silica removal from water, boiler feed preparations, chemistry of the hydrogen zeolite process, flow diagrams of hydrogen zeolite installations, methods and equipment used in industry, are included.

55 • SPECIAL ALLOYS. Duraloy Co. Bulletin on alloys for resistance to corrosion, high temperatures, and abrasion. Covers Duraloy static castings and Duraspun centrifugally cast tubes. Details the position of the company in the field, explains the Duralizing process for adding a surface resistance to castings against oxidation and abrasion, gives charts of corrosion resistance, alloy composition, various treatments, machinabilities, etc. Stress curves, etc. Specific uses are shown.

56 • KELLEX — ITS STORY. From The Kellex Corp., one of the first in the atomic energy field, an 18-page booklet describing its facilities and its work for the Atomic Energy Commission and Armed Services. Essentially a story of an engineering group. Gives personalities, staff, installation, etc., facilities of the company.

57 • SPLIT CASE CENTRIFUGE. Single-stage split case centrifugal pump, a late development of The Deming Co. Either direct connection to electric motor, steam turbine, gasoline engine, or belt drive. Capacities from 25,000 to 40,000 gals./min., heads 20 to 300 ft.

58 • BUBBLE-CAP ASSEMBLY. A 2-page data sheet from The Pressed Steel Co. on LeJons bubble-cap assembly. Features faster assembly and disassembly since the cap, riser and yoke come weld-assembled ready for wedging into position in tray. Designed to save construction and maintenance costs in tray construction. Requires no bolts or nuts. Reverse side lists more than 150 styles of standard bubble caps.

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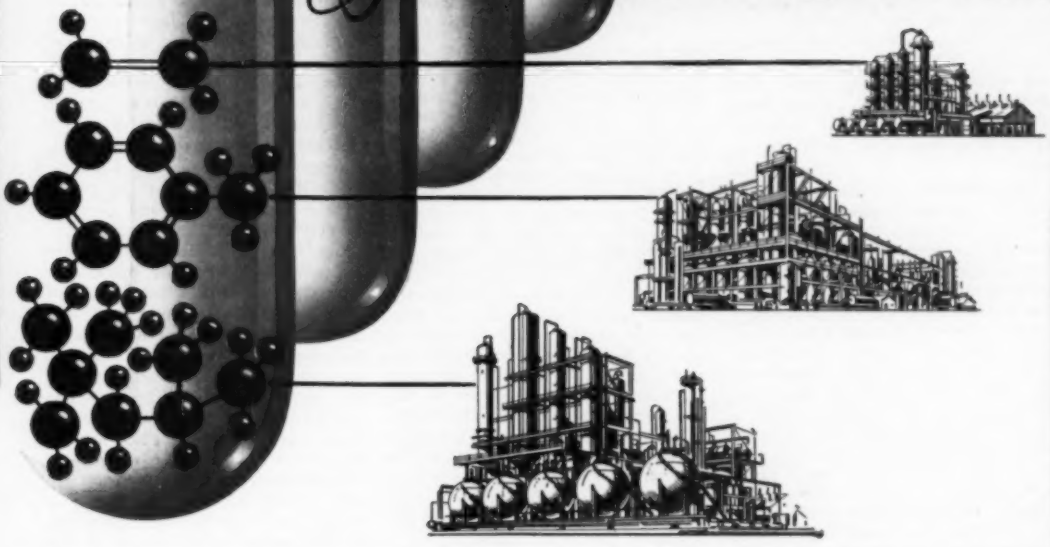

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

In a Class By Itself

Crystal Growth. H. E. Buckley. John Wiley & Sons, Inc., New York, N. Y. (1951) 571 pp. $9.00.

Reviewed by W. L. McCabe, Past President, A.I.Ch.E., and Vice-President, Flintkote Co., Whippany, N. J.

THIS excellent book presents a broad review of present experimental and theoretical knowledge of the subtle and important process of crystal growth. The literature on this subject is both extensive and diffuse. Much of it is in publications not usually accessible. Dr. Buckley has rendered a valuable service in assembling the data on crystal growth and critically reviewing them. The present volume provides the only comprehensive and authoritative treatment of crystal growth in the English language.

The material is assembled under the following general headings: solution, solubility, and supersolubility, with emphasis on the work of Miers, de Coppet, Tamman, Young, and others; practical methods of growing crystals, with emphasis on the art of growing large single crystals, and with a short discussion of some industrial methods; the various theories of crystal growth, starting with the older surface energy theory of Currie and others, and the diffusion theories of Noyes and Whitney, Berthoud, and Valeton, and concluding with detailed discussions of the recent structural theories of growth advanced by Niggli, Kossel, Stranski, and Volmer; the controversial subject of ideal vs. real crystals; miscellaneous methods of crystallization, including crystallization from melts, from the vapor phase, growth associated with chemical change, growth from electrodeposition, and growth in the solid state; the diverse phenomena accompanying the dissolution of crystals; crystal habit and its modification; various types of mixed crystallization and occlusions, including a short discussion of adsorption isotherms; and a treatment of a number of peculiarities of crystal growth.

The treatment is from a scientific, rather than from an engineering or technical, point of view. Industrial methods of processing are but lightly touched upon, and little attention is given to metallurgical problems. The topics covered are treated so well, however, and the amount of information that has been assembled is so large, so well organized, and so conservatively evaluated, that those interested in the scientific background of crystallization will welcome Dr. Buckley's volume.

Solving Problems the Engineering Way

The Engineering Method. Charles Lounsbury Fish. Stanford University Press, Stanford, Calif. (1950) 186 pp. $3.00.

Reviewed by Thomas K. Sherwood, Dean of Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

THIS is a somewhat detailed analysis and description of the engineering method of tackling problems and making decisions. The approach is logical to the point where the book might be described as an application of the engineering method to the problem of describing the engineering method. It does this well, but perhaps too thoroughly—few good engineers use such elaborate formal procedures in their thinking as those which the author describes. This fault is accentuated by the complicated diagrams used in the analysis of illustrative problems, and by the contrast between the properly simple problems used (which of three hats to buy) and the clumsy but logical nature of the formal approach described. The writing is just sufficiently complicated to require a number of definitions: "to evaluate the question" means "to find the answer to the question." One wonders why "answer" could not have been used for "evaluate."

The engineering teacher and practicing engineer will enjoy parts of the book, such as the description of John R. Freeman's selection of a water supply for San Francisco. The emphasis on the uncertainties and the necessity for judgment in engineering is excellent, e.g., "All larger engineering questions are questions of choice, and it is only among their subquestions—the questions as to the values of their factors—that the computable questions are encountered."

The book is a reprint of part of the larger volume, "The Engineering Profession" by J. T. Hoover and J. C. L. Fish (Stanford University Press, 1946). The worthwhile preface, "The Grand Strategy of the Engineer" is quoted from a 1925 address by Prof. William F. Durand.

Behaviorism in Metallurgy

The Behavior of Engineering Metals. H. W. Gillett. John Wiley & Sons, Inc., New York, N. Y. (1951) 395 pp. $6.50.

Reviewed by Norman S. Mott, Chief Chemist and Metallurgist, The Cooper Alloy Foundry Co., Hillside, N. J.

DR. GILLETT'S book encompasses the extremely wide field of metallurgy in such a manner as to provide the not-too-technical individual with a practical working knowledge of its fundamentals and manipulations. This book should enable inspectors, designers, purchasing agents, construction engineers, and the like to perform their duties more satisfactorily based upon an understanding of metallurgical principles and practices involved, and offers a foundation for more extended study in any metallurgical field of special interest. Pertinent references given in the text are helpful in this respect.

The up-to-date and modern coverage ranges through the basic concepts of metallurgy, the behavior of metals and alloys including the newer and less-known metals titanium and zirconium, the technological manipulation of metals, inspection and control testing, economic and availability considerations, and also such unique subjects as the metallurgical requirements of atomic energy applications.

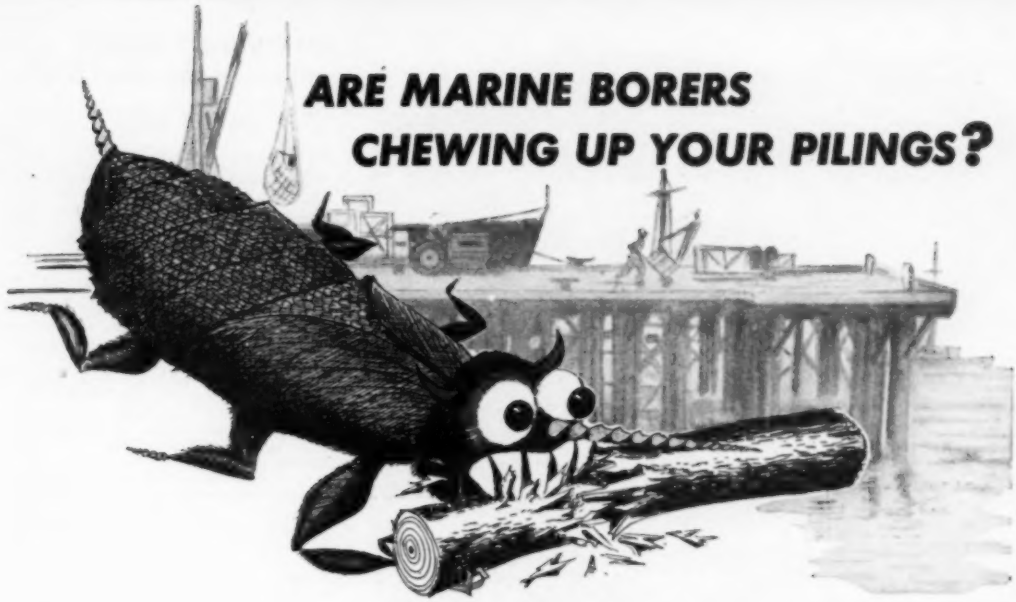
Great regret is expressed that the author, who so ably and thoroughly brought highly technical metallurgy to a level of understanding suitable for the nontechnical and practical man, will not be able to see the extent of popularity and acclaim that this book is sure to acquire—the author died recently.

Books Received

Medicinal Chemistry. Vol. 1. A series of reviews prepared under the auspices of the division of medicinal chemistry of the American Chemical Society. John Wiley & Sons, Inc., New York, N. Y. (1951) 473 pp. $12.00.

Progress in Chromatography, 1938-1947. L. Zechmeister. John Wiley & Sons, Inc., New York, N. Y. (1951) 368 pp. $8.00.

The Chemistry of Hydrazine. L. F. Audrieth and Betty Ackerson Ogg. John Wiley & Sons, Inc., New York, N. Y. (1951) 244 pp. $5.00.



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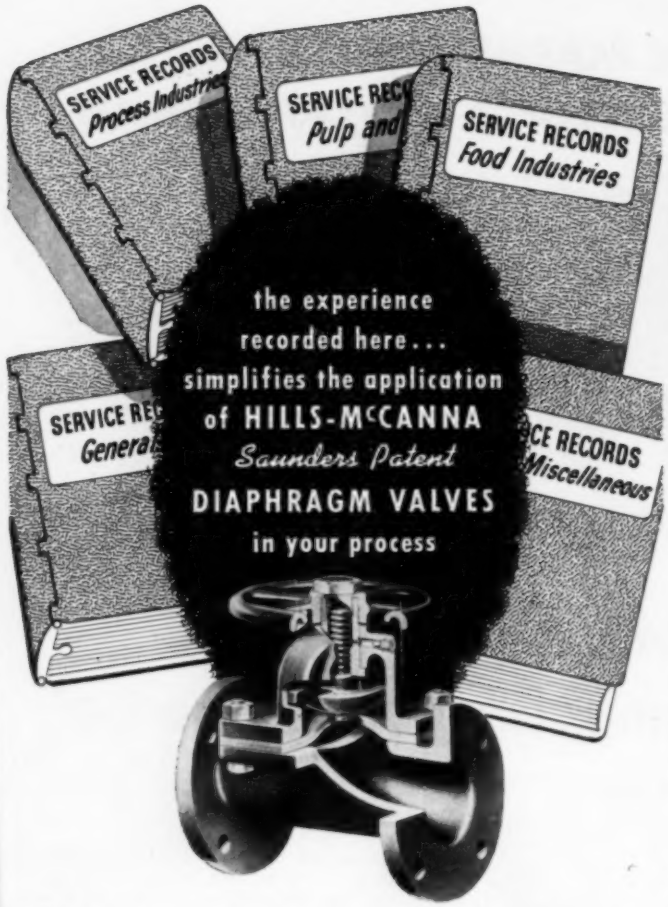

If you are conveying corrosive or hard-to-handle fluids, a Saunders Patent Diaphragm Valve may be the answer to your valving problems. If so, the experience recorded in the five volumes illustrated above is your best assurance of getting the *right* valve for your needs. In these records are body and diaphragm material recommendations for handling some 2500 substances, based on Hills-McCanna's nearly 20 years' experience in the manufacture and application of Saunders Patent Valves. If you have a tough valving problem, let this "know-how" work for you.

Hills-McCanna Saunders Patent Diaphragm Valves are made in sizes from ⅜" to 14" for manual, automatic or remote operation with a choice of 13 diaphragm materials and 48 body materials. Write for complete information. HILLS-McCANNA CO., 2438 W. Nelson St., Chicago 18, Ill.

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AN ENGINEER LOOKS AT U.N.E.S.C.O.

By R. M. GATES

1. UNESCO, the United Nations Educational, Scientific, and Cultural Organization, started out with a mandate "to contribute to peace and security by promoting collaboration among the nations" by activities in the three fields mentioned in its title. But education, science, and culture are very broad terms. . . . . In response to pressures from many sources, it tried to spread its limited resources and facilities over a wide range of projects . . . .

2. Some of these activities, nevertheless, have already shown worthwhile results. In three years voluntary groups in the United States were responsible for sending over $200 million worth of materials and supplies for reconstruction of educational, scientific, and cultural institutions in war-devastated countries. UNESCO was active in publicizing needs and the Commission for International Educational Reconstruction in this country coordinated and stimulated the activities of voluntary organizations related to educational reconstruction. . . . . And not least in importance, the bringing together of scientists, educators, sociologists, and others from many nations, to canvass needs . . . . has obviously been a substantial contribution to mutual understanding among leaders in those fields . . . .

3. The experience of the past three or four years has led to some shaking down of the diffuse UNESCO program, and it appears that this process will continue. . . . .

4. The United States National Commission for UNESCO, set up by act of Congress in 1946, is designed to furnish UNESCO advice and support. It has 100 members, of whom 60 are nominated by voluntary organizations in educational, scientific, and cultural fields and 40 represent federal and state governments and broadly the public at large. . . . . The members of the National Commission have naturally had the same difficulty as the members of UNESCO in reaching a consensus. . . . .

5. It seems to an engineer (1) that theory is more largely represented than practice on these bodies; (2) that the engineering profession ought to be more largely represented on both UNESCO and the United States National Commission, for many of the things that need most to be done "to contribute to peace and security" are in part or in essence engineering jobs; and (3) that "science" should be interpreted to include applied science, instead of mainly "pure" science . . . .

6. Whether or not adequately represented on UNESCO and the United States National Commission, the organizations of engineers in this country and abroad can do much to serve . . . . UNESCO . . . .

Iron curtains offer the least resistance to engineering . . . . Even within the Soviet orbit, engineers probably take less seriously than most others the official Communist interpretation of American attitudes and purposes, because they get direct and objective information of the activities of fellow-engineers in the free nations. And peoples not yet behind the iron curtain may be helped to stay outside if engineering aid

Mr. Gates is E.J.C. Representative on U. S. National Commission for UNESCO.

(*Continued on page* 51)

E.J.C. CALLS FOR MORE ENGINEERS

The Engineering Manpower Commission of Engineers' Joint Council, of which A.I.Ch.E. is a member, has issued a call to principals, vocational councilors, and guidance teachers, in the high schools throughout the land, to publicize the current shortage of engineering men.

E.J.C. mailed to 23,000 high school principals a circular detailing the present critical shortage. A copy of "Engineering As A Career," was also included with the pamphlet.

In a release which went to the nation's newspapers, E.J.C. called for doubling the present enrollment for years to come.

According to W. A. Marshall, Jr., executive secretary of the Manpower Commission, 60,000 freshmen are called for in future enrollments. This, he said, would produce 30,000 graduates each year. He also predicted a shortage of 40,000 engineers by 1954.

URANIUM REFINERY AT CINCINNATI

The United States Atomic Energy Commission will construct a uranium ore refinery and other facilities for the production of uranium feed materials on a 1,200-acre site near the Miami River, 19 miles northwest of downtown Cincinnati, Ohio. The new installation will produce uranium in forms suitable for use in the A.E.C.'s fissionable materials production plants.

The new facilities are being designed by Catalytic Construction Co., Philadelphia. Acquisition of the land will be undertaken by the Louisville (Ky.) District Office of the Corps of Engineers and construction will begin as soon as right of entry to the site has been obtained. Final selection of construction and operating contractors has not yet been made.

Selection of the site was made after a three-month survey by the Commission's New York Operations Office and the Catalytic Construction Co. Divisional offices of the Corps of Engineers and industrial representatives of ten railroads serving the Midwest and South assisted in the survey.

The A.E.C. stated that no atomic weapons would be made at the site and that operations there would create no environmental toxic or radiological hazards.

The cost of the new Feed Materials Production Center is estimated to be at least $30,000,000. A permanent operating force of about 1,200 will be required.

(More News on page 40)

A COMPLETE TECHNICAL SERVICE by ANSUL
EFFECTIVE AND ECONOMICAL USES OF SO_2 IN A VARIETY OF INDUSTRIES
ANSUL SO_2 IN INDUSTRY
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CONSULT ANSUL'S STAFF of trained and experienced Chemical Engineers.
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Call on them for assistance, without cost or obligation.
Ansul's Technical Service gives you the benefits of improved process efficiencies and quality control when using Ansul Liquid Sulfur Dioxide.
New uses of liquid sulfur dioxide are continually being developed. It's HIGH PURITY, GREATER ECONOMY, AND EASE OF CONTROL provide a versatile and effective chemical to a great variety of industries.
To compliment the availability of liquid sulfur dioxide, Ansul has cataloged years of experience and research to provide a complete technical service covering present and potential uses of SO_2 in industry.
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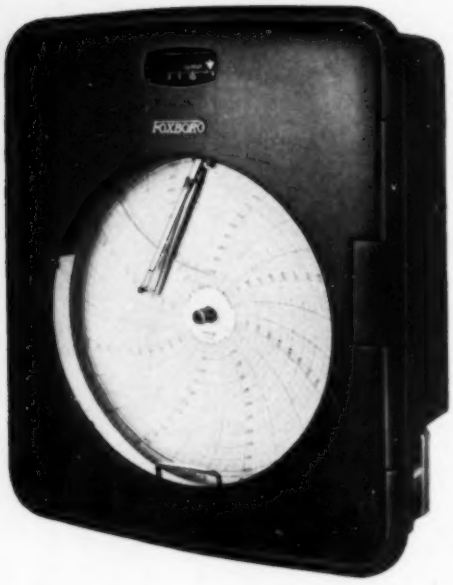

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TREASURER'S REPORT

The accompanying balance sheet and statement of income and surplus have been examined by F. W. Lafrentz & Co., certified public accountants of 100 Broadway, New York, N. Y., and in their opinion present fairly the financial position of the American Institute of Chemical Engineers at December 31, 1950, and the results of its operation for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

C. R. DE LONG, *Treasurer.*

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS
COMPARATIVE BALANCE SHEET
DECEMBER 31, 1950 and 1949

Assets

	1950		1949	
Current Assets:				
Cash on hand and demand deposits		$115,214.70		$ 97,736.43
U. S. Government and other bonds, at cost plus accrued interest (Total market value and redemption value 1950, $74,450.50; 1949, $61,596.75)		74,427.36		61,049.36
Accounts Receivable:				
Membership dues, less reserve for doubtful accounts	$ 926.10		$ 770.87	
Entrance fees	270.00		100.00	
Advertising	2,130.23		2,847.62	
Publications and advances	1,230.53		606.72	
Meetings advances	800.00	5,366.86	3,912.75	8,237.96
Inventory at Cost:				
Paper stock	$ 5,000.46		$ 9,854.96	
Stamped envelopes	538.13	5,538.59	518.38	10,373.34
Total Current Assets		$200,547.51		$177,397.09
Deposits:				
United States Post Office	$ 356.36		$ 707.22	
United Airlines, Inc.	425.00	781.36	425.00	1,132.22
Furniture and fixtures, at cost	$ 16,211.41		$ 13,447.68	
Less reserve for depreciation	7,174.56	9,036.85	5,553.41	7,894.27
Deferred charges		$ 1,792.48		
Total		$212,158.20		$186,423.58

Liabilities

Current Liabilities:				
Accounts payable:				
Printing and other expenses		$ 7,074.26		$ 11,168.05
Total current liabilities		$ 7,074.26		$ 11,168.05
Deferred Income:				
Dues paid in advance	$ 62,667.26		$ 63,106.55	
Subscriptions	12,584.76		13,381.76	
Other payments received in advance	2,041.40	77,293.42	355.20	76,843.51
Reserves:				
Chemical Engineering Education Projects Fund	$ 1,912.21		2,164.39	
Student Meetings Fund	41.26		41.26	
Magazine Publication Program	17,873.91	19,827.38	13,871.16	16,076.81
Surplus		107,963.14		82,315.21
Total		$212,158.20		$186,423.58

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS
COMPARATIVE STATEMENT OF INCOME AND SURPLUS
FOR THE YEARS ENDED DECEMBER 31, 1950 and 1949

	1950		1949	
INCOME:				
Membership dues	$146,712.31		$137,258.00	
Less amount allocated to subscriptions @ $4.50 per member	44,924.18	$101,788.13	42,069.75	$ 95,188.25
Entrance fees		11,485.00		13,450.00
Magazine income		162,399.04		153,640.60
Bound volumes and Transactions, net sales		826.45		1,457.53
Institute Meetings:				
Surplus	$ 3,928.30		$ 2,059.46	
Less expense	709.30	3,219.00	658.73	1,400.73
Emblem sales	$ 2,399.50		$ 3,102.25	
Less purchases	1,772.65	626.85	2,239.02	863.23
Interest on investments		1,765.50		1,933.50
Total Income		$282,109.97		$267,153.84

EXPENSES:	1950		1949	
General Operations:				
Magazine expenses	$ 90,029.91		$ 97,103.16	
Salaries	97,030.58		93,090.22	
Employees Retirement Plan	5,939.33		.....	
Rent and Electricity	12,552.69		12,564.70	
Postage	6,394.46		5,552.59	
Telephone and Telegraph	2,379.31		2,250.34	
Stationery and office supplies	2,514.19		2,052.77	
Auditing	1,075.91		1,310.50	
Travel	2,235.76		1,673.13	
Provision for depreciation of furniture and fixtures	1,621.15		1,344.77	
Provision for doubtful accounts	3,045.27		2,326.53	
Workmen's Compensation Insurance	121.08		.....	
Miscellaneous	3,048.11	$227,987.75	2,703.33	$221,972.04
Institute Meetings:				
Programs	$ 4,542.86		$ 4,387.16	
Travel	1,937.65		1,845.58	
Other	1,056.68	7,537.19	1,126.25	7,358.99
British Transactions purchased †				11,411.08
Printed Material:				
Directory	$ 7,102.87		$ 372.30	
Ballot booklets, letterheads, envelopes, etc.	4,251.07	11,353.94	5,251.64	5,623.94
Participations and Contributions:				
American Standards Association	$ 500.00		.....	
Engineers' Council for Professional Development	600.00		$ 336.50	
Engineers' Joint Council	234.90		232.50	
The Chemists' Club Library	100.00		100.00	
Engineering Societies Library	100.00		100.00	
National Water Policy Study Panel	288.00		.....	
American Society for Engineering Education	50.00		50.00	
U. S. National Committee on Theoretical and Applied Mechanics	50.00		50.00	
American Documentation Institute	25.00	$ 1,947.90	25.00	$ 894.00
Committee Appropriations:				
Council	$ 403.08		$ 406.61	
Admissions	365.34		531.91	
Awards	463.49		315.79	
Chemical Engineering Education and Accrediting	147.49		250.65	
Constitution and By-Laws	362.45		424.11	
Ethics	250.00		.....	
Local Sections	166.69		85.44	
Membership	97.31		.....	
Patents	200.00		200.00	
Professional Guidance	11.02		.....	
Program	97.13		114.56	
Public Relations	447.43		152.74	
Student Chapters	586.09		1,132.02	
Symbols and Nomenclature	34.99	3,632.51	.....	3,613.83
Total Expenses		$252,459.29		$250,873.88
Net Income for year		$ 29,650.68		$ 16,259.96
Surplus at Beginning of year		96,186.37		79,926.41
		$125,837.05		$ 96,186.37
Deduct:				
Reserve for Magazine Publication program		$ 55,000.00		$ 55,000.00
Less net expenditure to end of year		37,126.09		41,128.84
Magazine Publication program		$ 17,873.91		$ 13,871.16
Surplus at End of Year		$107,963.14		$ 82,315.21

† Subsequent years transactions were purchased and resold.

SECRETARY'S REPORT

S. L. TYLER

THE Executive Committee met at The Chemists' Club April 6. After receiving the Treasurer's report and approving bills for payment the first order of business was the election of new members of which 144 were elected to Student membership; those listed in the March, 1951, Chemical Engineering Progress were elected to the grades indicated.

R. M. Torrey was appointed to the Committee on Admissions to replace W. I. Burt who had resigned. W. B. Polk was appointed a member of the Public Relations Committee. T. B. Drew was appointed Institute representative on the EJC Committee on Engineering Sciences. J. M. Church was appointed Institute representative on the ECPD Student Development Committee. L. W. Bass, R. P. Kite and N. A. Shepard were appointed alternates to our regularly designated representatives in accordance with the rules of the Perkin Medal Committee. These representatives are W. L. McCabe as Past President, T. H. Chilton as President and W. I. Burt as Vice President.

Resignations of 15 members were accepted in good standing.

Four elections to Junior membership were rescinded for non-acceptance.

Secretary reported the addition of the following names to the Suspense List because of their entrance into the Armed Forces: F. S. Chalmers, J. G. Hayes, T. V. McGannon, Jr., P. K. Mulvany and R. S. Williams.

(*Continued on page 37*)

ASBESTOS CANNOT CARBONIZE—IT ENDURES FOREVER

AVOID THIS! ◆

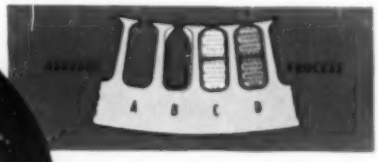
U. S. MOTORS

are asbestos-protected

Life of a motor is proportional to the life of the insulation protecting its windings. While there is no way to guarantee perpetual life, there *is* a method of insulating the windings so that life will be infinitely increased—by using *asbestos insulation*. That is the proved element used in insulating the windings in U. S. Motors. Asbestos is the greatest of all pliable, heat-resisting materials.

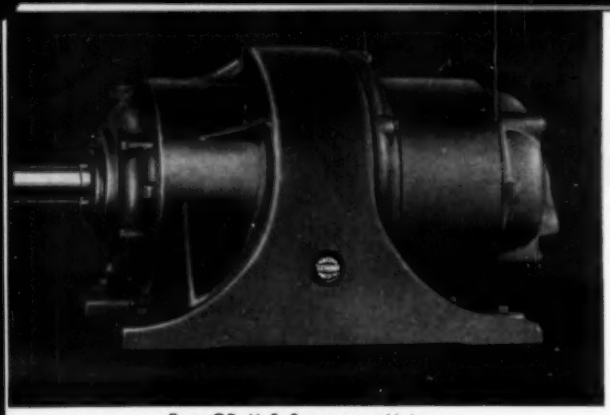
U. S. WINDINGS MOST RESISTANT TO HEAT

A burnt-out motor is evidence that the windings have failed. Commonly used cellulose materials can carbonize, changing from insulator to conductor, whereas asbestos is a fibrous rock whose silken fibres can turn red hot but *cannot carbonize*. U. S. windings are forever protected.



(A)—Empty stator slot before insulating and winding. (B)—Formed cell of asbestos providing a heat-proof wall of insulation. (C)—Cross section showing wires inserted, with asbestos cell covering entire winding. Asbestos plateboard in center of slot separating and insulating between coils. (D)—Asbestosite (in color) forced around windings, penetrates every interstice.

(See next page)



Type GD, U. S. Syncrogear Motor

Type VE, U. S. Horizontal Varidrive Motor

Type SE or SD, U. S. Totally-Enclosed Fan-cooled Motor

U. S. MOTORS

offer these advanced features:

ASBESTOS-PROTECTED WINDINGS
NORMALIZED CASTINGS
ANNEALED STEEL LAMINATIONS
SOLID CENTRICAST ROTORS
DUAL CYCLONE VENTILATION
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STREAMLINED, SHIELDED HOUSINGS

Since the inception of U. S. Motors in 1908, a highly successful principle has been maintained—*to build up to a quality*, not down to a price. You can sense U. S. quality in the appearance of these motors. But even more impressive are the many advanced features that insure longest life.

Every U. S. Motor is asbestos-protected—because asbestos *cannot* carbonize. This is an exclusive U. S. feature. By normalizing castings, bearing alignment is maintained so that destructive stresses cannot occur. Lubriflush lubrication presents a convenient means of purging the bearings of old, worn-out grease and replacing the entire bearing chamber with new lubricant without disturbing the bearing setting. The bearings are also self-lubricated for normal life so that even if the old grease is never replaced, bearings are protected.

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SECRETARY'S REPORT

(*Continued from page 34*)

1949 Transactions—The Institution of Chemical Engineers

The 1949 Transactions of The Institution of Chemical Engineers (London), Volume 27, will be available in the relatively near future. As in previous years these Transactions are available on an individual order basis. The price will be $5.25. Orders should be placed promptly with the office of the Secretary, 120 East 41st St., New York 17.

This volume contains the usual information such as names of officers and Council for 1949, annual report of Council and balance sheet for 1948.

The following articles are also included:

Conference on Drying:

The Mechanism of the Drying of Solids. Part I. *The Forces Giving Rise to Movement of Water in Granular Beds During Drying*—J. F. Pearse, T. R. Oliver and D. M. Newitt. Part II. *The Measurement of Suction Potentials and Moisture Distribution in Drying Granular Solids*—T. R. Oliver and D. M. Newitt.

Vacuum Freeze Drying—H. H. Chambers.

Drying Machinery and Its Development—E. F. Mactaggart.

Radio Frequency Drying—R. L. Stephens.

The Catalytic Cracking of Acetic Acid for the Production of Acetic Anhydride—L. W. J. Loveless.

Materials of Construction for Use at Low Temperatures—E. W. Colbeck.

Developments in the Use of Climbing-Film Stills for the Distillation of Heat-Sensitive Materials—C. H. G. Hands and W. S. Norman.

Some Applications of Vacuum to Industrial Chemical Processes—J. Leyland.

Production of Vacuum for Industrial Chemical Processes—G. Arrowsmith.

Solvent Extraction as a Unit Process—J. C. Wood-Mallock.

An Approach to Continuous Twitchell Fat Splitting—C. B. Cox.

The Fabrication of Chemical Plant in Stainless Steel—A. C. Branch and J. L. Sweeten. (Awarded the Moulton Medal 1949).

The Production of Ammonia Synthesis Gas from Wood Fuel in India—R. W. Rutherford and K. Ruschin.

Heat Transfer in Condenser-Evaporator Units Used in Air Separation—M. Guter.

Heat Transfer from Condensing Oxygen and Nitrogen Vapours—G. G. Haselden, and S. Prosad.

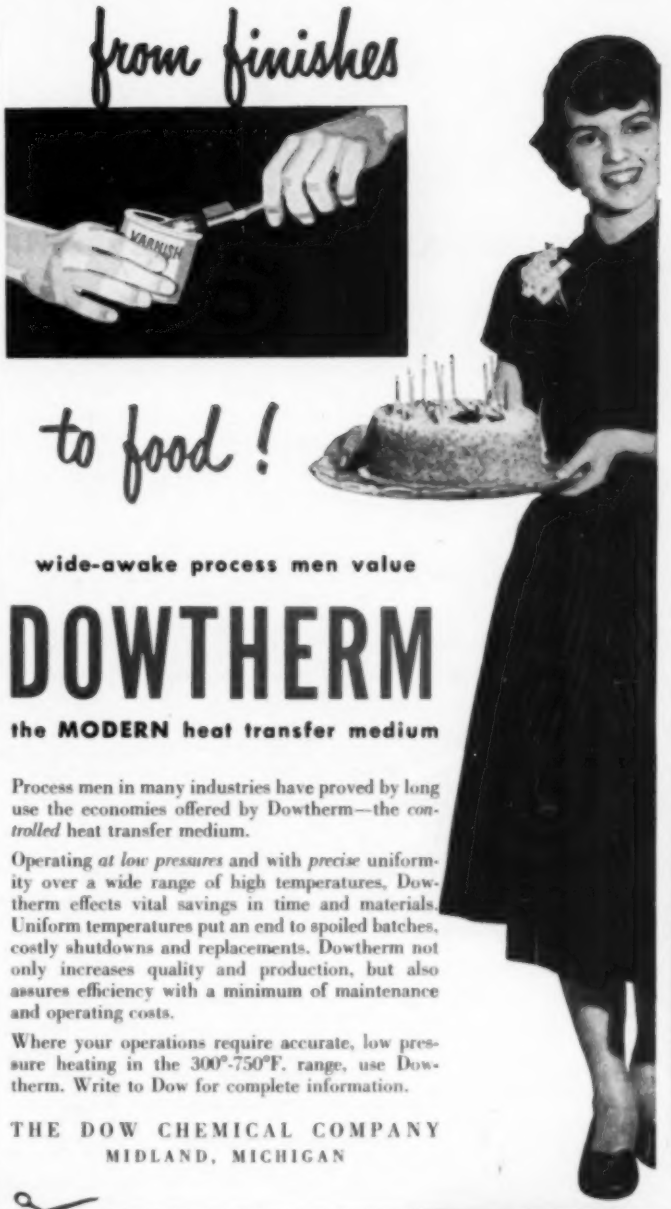
Heat Transfer to Boiling Liquid Oxygen and Liquid Nitrogen—G. G. Haselden and J. I. Peters.

Recent Developments in Submerged Combustion—N. Swindin.

The Composition of Fractionating Column Products under Various Reflux Conditions—J. S. Forsyth and N. L. Franklin.

The Flow of Fluids Through Granular Beds: Effect of Particle Shape and Voids in Streamline Flow—J. M. Coulson.

The Mechanism of the Displacement of Liquids from Porous Solids—D. I. W. Atkinson (Awarded the Junior Moulton Medal 1949).



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INDISPENSABLE TO INDUSTRY AND AGRICULTURE

CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E. which states:

Election to membership shall be by vote of the Council upon recommendation of the Committee on Admissions. The names of all applicants who have been approved as candidates by the Committee on Admissions, other than those of applicants for Student membership, shall be listed in an official publication of the Institute. If no objection is received in writing by the Secretary within thirty days after the mailing date of the publication, they may be declared elected by vote of Council. If an objection to the election of any candidate is received by the Secretary within the period specified, said objection shall be referred to the Committee on Admissions, which shall investigate the cause for such objection, holding all communications in confidence, and make recommendations to the Council regarding the candidate.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before *June 15, 1951*, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st St., New York 17, N. Y.

APPLICANTS FOR ACTIVE MEMBERSHIP

Herman E. Bakken, *St. Louis, Mo.*
Walter C. Brandsma, *Marshalltown, Del.*
Abbott Byfield, *Neenah, Wis.*
W. H. Cain, *Cuyahoga Falls, O.*
Harris P. Child, *Carney's Point, N. J.*
David B. Coghlan, *Arden, Del.*
Lewis S. Coonley, *Troy, N. Y.*
Floyd L. Corson, *Brookfield, Ill.*
James F. Elrod, *El Dorado, Ark.*
Ray M. Ewald, *Kirkwood, Mo.*
Gerald L. Farrar, *College Station, Tex.*
Edwin H. Garretson, *Rochester, N. Y.*
Forrest E. Gilmore, *Bartlesville, Okla.*
Emmanuel H. Guillis, *Clifton, N. J.*
Kenneth R. Hancock, *E. St. Louis, Ill.*
J. W. Hemphill, *New York, N. Y.*
Byron N. Inman, *Kenmore, N. Y.*
George Kazan, Jr., *Arden, Del.*
Fred J. Kirkish, *Tarrytown, N. Y.*
John W. Levergood, *Clairton, Pa.*
John H. Lovett, *Chicago, Ill.*
Clyde H. Mathis, *Borger, Tex.*
Alex Newhouse, *Waynesville, N. C.*
J. Robert Powers, *New York, N. Y.*
H. D. Radford, *Texas City, Tex.*
Richard L. Ramsey, *Milwaukee, Wis.*
J. S. Rearick, *New York, N. Y.*
B. A. Rocca, *Toronto, Ont., Canada*
Frank H. Sanders, *Bartlesville, Okla.*
B. R. Sarchet, *Beaver, Pa.*
Enno T. Sauer, *Philadelphia, Pa.*
George F. Schlaudecker, *Toledo, Ohio*
M. W. Shellenbarger, *Merchantville, N. J.*
Frank G. Smith, Jr., *Louisville, Ky.*
S. C. Streep, *Baltimore, Md.*
Robert L. Teeter, *Pittsfield, Mass.*
Edward F. Thode, *Orono, Me.*
Wm. E. Tucker, Jr., *New York, N. Y.*
Andrew W. Williams, *Wilmington, Del.*
Dwight Williams, *Charleston, W. Va.*
Donald E. Womeldorph, *Wilmington, Del.*

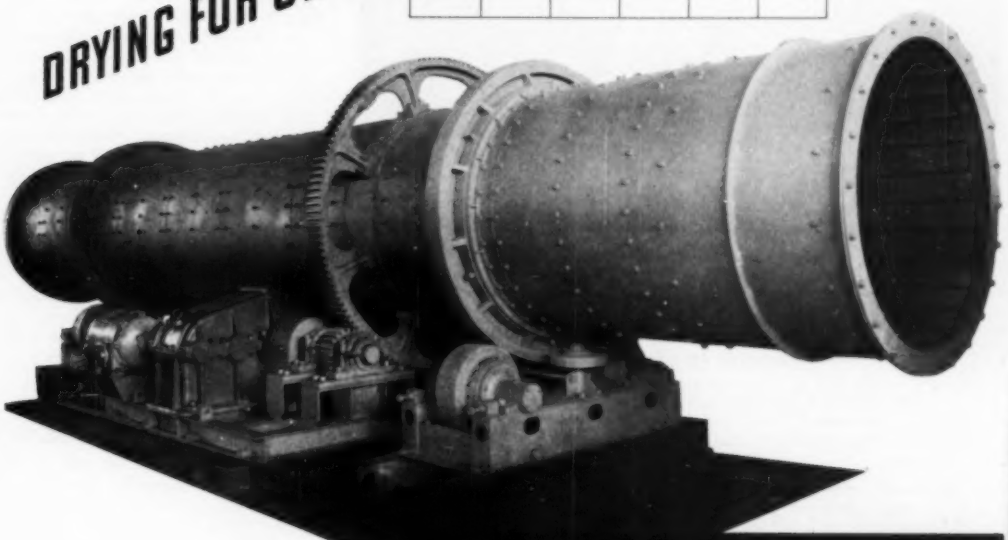
APPLICANTS FOR ASSOCIATE MEMBERSHIP

Olin F. Hardy, Jr., *Maplewood, La.*
Henry James Hess, *Elizabeth, N. J.*
M. A. Witte, *Oklahoma City, Okla.*

APPLICANTS FOR JUNIOR MEMBERSHIP

Charles N. Abbott, *Dayton, Ohio*
John H. Barker, *Springfield, Mass.*
William G. Barker, *Maplewood, Mo.*
Theodore R. Beck, *Seattle, Wash.*
James S. Benson, *Cleveland, Ohio*
Edward H. Berg, *Woodstown, N. J.*
M. B. Bhate, *Brooklyn, N. Y.*
George H. Black, *Baltimore, Md.*
Hampton Miller Burt, *Talladega, Ala.*
D. T. Campbell, *Devon, Alta., Canada*
Robert A. Campbell, *Hermosa Beach, Calif.*
William J. Chambers, Jr., *Oak Park, Ill.*
Alberto Chamorro-B, *Granada, Nicaragua, C. A.*
Lewis H. Conklin, *Cuyahoga Falls, Ohio*
James R. Couper, *St. Louis, Mo.*
Robert L. Daileader, *Bellerose, N. Y.*
Charles J. Davis, Jr., *Pittsburgh, Pa.*
Donald T. Day, *Metuchen, N. J.*
Milton L. Dunham, Jr., *Tonawanda, N. Y.*
Roy T. Eby, *Texas City, Tex.*
Ernest L. Fallwell, *Wilmington, Del.*
Thomas A. Feazel, *Baton Rouge, La.*
John R. Ferron, *Niagara Falls, N. Y.*
Joseph Flum, *Brooklyn, N. Y.*
Herbert M. Fried, *Yonkers, N. Y.*
Richard Gustafson, *Beaver, Pa.*
Thomas A. Haverfield, *Akron, Ohio*
Robert D. Jeep, *Kirkwood, Mo.*
Frederick A. Kays, Jr., *Kingsport, Tenn.*
Joe T. Kelly, *Texas City, Tex.*
Robert E. Logsdon, *Chicago, Ill.*
William D. Luker, *Savannah, Ga.*
Donald H. MacDonald, *Berea, Ohio*
Sebastian A. Marino, *Longmeadow, Mass.*
George J. Marlowe, *Somerville, N. J.*
Harold F. Mason, *Bristol, Pa.*
Benjamin T. McGill, *Freedom, Pa.*
Paul Merisge, *St. Louis, Mo.*
Robert W. Morrison, *Crystal Lake, Ill.*
Gordon H. Pedersen, *Madison, Wis.*
Miroslav J. Pistek, *Brooklyn, N. Y.*
Adam J. Pow, Jr., *Birmingham, Ala.*
R. R. Purohit, *West End, Calif.*
John Nelson Reeds, *Akron, Ohio*
Robert N. Secord, *Boston, Mass.*
V. V. Shah, *Delhi, India*
Robert D. Sinner, *Ames, Iowa*
Francis K. Smith, *Westernport, Md.*
M. Bruce Smith, *Wheaton, Ill.*
Albert J. Stevens, *Philadelphia, Pa.*
Richard O. Stucker, *Newark, Ohio*
Robert Thomson, *Charleston, W. Va.*
Don R. Tucker, *Louisville, Ky.*
R. P. Webb, *Hermosa Beach, Calif.*
John Weingarten, *Philadelphia, Pa.*
Henry Wigton, *Boulder, Col.*
G. J. Williamson, *Springfield, Mass.*
Samuel C. Williamson, *Pitcairn, Pa.*
Alfred E. Withrow, *Dayton, Ohio*
Harry P. Wood, *Oak Ridge, Tenn.*
Chang-Lee Yang, *Cincinnati, Ohio*

DRYING FOR GREATER PROFITS...



WITH STANDARD-HERSEY ROTARY DRYERS

MORE THAN 30 TYPES OF STANDARD-HERSEY DRYERS ARE AVAILABLE IN ALL COMMERCIAL SIZES FOR EVERY PROCESS INDUSTRY NEED

• Here is a case where Standard-Hersey advanced engineering has made teamwork pay dividends in stepping up production of artificially colored roof granules.

With the previous system, consisting of dryer, kiln and cooler, in series, it was found that production was being limited by dryer capacity.

Addition of the Standard-Hersey *pre-heater*, shown above, rounded out the team. It works like a double header locomotive in sharing the dryer load and thereby cutting drying stage time. Urgent production schedules are being met at much lower cost than the outlay for a second complete 3-unit plant.

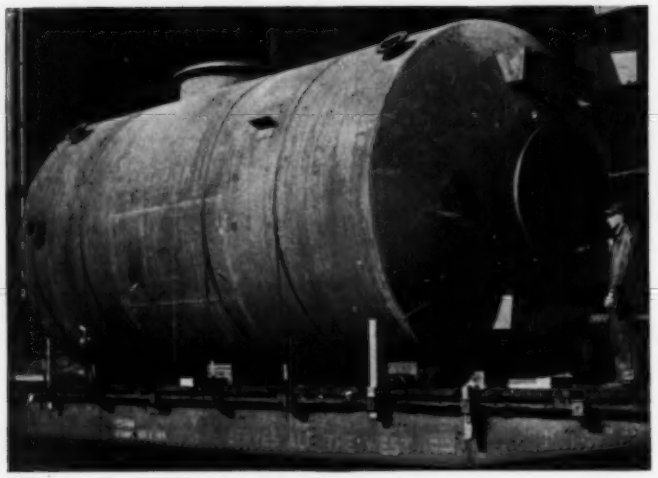
SEND FOR NEW DRYER BULLETIN

Complete illustrated brochure describing advantages and features of Standard-Hersey Dryers, Kilns, Coolers and Calciners; tells operation of Standard-Hersey "pilot" dryer for pre-testing your product. *Write for Dryer Bulletin No. 508.*

STANDARD HERSEY *Dryers*

STANDARD STEEL CORPORATION

5055 BOYLE AVE., LOS ANGELES 58 • 123-55 NEWBURY ST., BOSTON 16



Pyroflex constructed HCl cooling tower.

PYROFLEX CONSTRUCTIONS

Typical Installations

This engineered functional equipment combines the positive corrosion protection of Pyroflex sheet lining with the rugged strength of acid-proof masonry. However, Knight uses many other types of materials depending on service.

EQUIPMENT	OPERATING CONDITIONS		TIME IN SERVICE
	Service	Temp.	
Absorption Tower	SO_3 Gas, H_2SO_4 and Water	700°F	4 yrs.
Chlorinator	Chlorine Benzol and Chlorobenzol	50°F	3 yrs.
Acid Mist Extractor	H_2SO_4 Mist, HCl Gas and Water	250°F	6 yrs.
Cooling Tower	Conc. H_2SO_4 and HCl Gas	1100°F	10 yrs.
Drying Tower	Conc. H_2SO_4 and Chlorine Gas	90°F	5 yrs.
Pickling Tank	30% H_2SO_4	230°F	8 yrs.
Storage Tank	33% HCl and Traces Organic Solvents	85°F	7 yrs.

Autoclaves
Absorbers
Acid Boilers
Concentrators
Distillation Towers
Gas Coolers
Gas Washers
Acid Storage Tanks
Plating Tanks
Scrubbers
Sumps
Tanks

When inquiring about Pyroflex Constructions, please specify type of equipment in which you are interested as well as service conditions involved. Bulletin No. 2-F will be sent on request.

Maurice A. Knight 705 Kelly Ave., Akron 6, Ohio
Acid and Alkali-proof Chemical Equipment

(*News continued from page 31*)

UNIV. OF TENNESSEE GIVES PH.D. DEGREE

The first Doctorate in chemical engineering conferred by the University of Tennessee was awarded to F. S. Chance, Jr., at the March commencement exercises. Chance, a B.S. graduate of the University of Tennessee in 1937, is now employed by Chas. Pfizer & Co., Inc.

The doctoral program of the University of Tennessee is relatively new; the board of trustees of the University, of which Governor Browning of Tennessee is a member, gave permission to grant such a degree in chemical engineering in September, 1950. The University has granted M.S. degrees in chemical engineering for 16 years and at present, chemical engineering is the only engineering department of the college to grant Ph.D. degrees.

The University now has six additional students working on doctoral researches.

The first B.S. at the University in chemical engineering was granted in 1908. The chemical engineering department was split off from the chemistry department in 1936, and was accredited by A.I.Ch.E. in 1939.

DOW TO OPERATE NEW A.E.C. PLANT

The United States Atomic Energy Commission recently announced a new production plant which will be built on a four-square mile site in the rocky flats area of Boulder and Jefferson Counties, Col. Acquisition of land for the new facility, a secret type of operation, will begin immediately by the Missouri River division, Corps of Engineers, Department of the Army.

Estimated cost of the facility is $45,000,000.

The Dow Chemical Co., Midland, Mich., will operate the plant and has assisted in establishing production requirements and site criteria. It is expected 1,000 persons will be employed when full operations commence. F. H. Langell of Dow will manage the plant.

STANDARD STOKER NOW READ STANDARD

The Standard Stoker Co., Inc., has changed its corporate name to Read Standard Corp. This is a change in name only with no change in ownership, management or personnel.

The company products now include Readco chemical processing equipment, bakery machinery and ovens, products heretofore of Read Machinery Division. In addition, axial flow positive pressure Standardaire blowers for varied industries, and Standard stokers for railroad and industrial use, are made by the corporation.

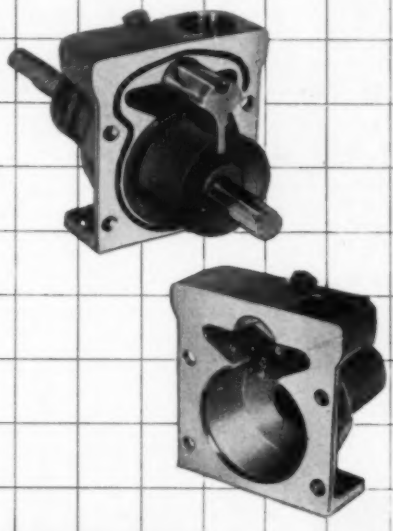
ONCE A SPECIALTY... **NOW MASS-PRODUCED**

PRODUCTION OF STAINLESS STEEL PUMPS FAST and ECONOMICAL WITH "HAYNES" PRECISION CASTINGS

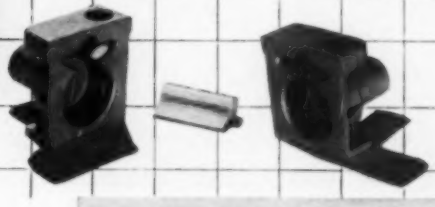
Stainless steel gearless pumps were strictly a "specialty" item with a New Jersey pump manufacturer until investment castings were put to work. They are now being mass-produced as a standard item.

Fabrication of the pumps is easy and economical. The precision investment castings—two body sections and an impeller guide—require only a few finishing operations before assembly because they are cast so close to size. For this reason, there is no excessive waste in machining. The parts have a sound, dense structure, and the surfaces are exceptionally smooth. Even the lettering that identifies the manufacturer, the model, and the patent numbers is cast so precisely that it is clear and legible.

Use of HAYNES precision investment castings has thus made it possible to produce pumps with excellent appearance and long service life at attractive prices. For examples of other successful applications of these castings, and also tips on designing parts to be produced by this method, write for the booklet, "Investment Castings."



Use of investment castings (right) for the three metal parts of stainless steel gearless pumps (above) has enabled a New Jersey manufacturer to mass-produce the pumps.



HAYNES TRADE-MARK *alloys*

"Haynes" is a trade-mark of Union Carbide and Carbon Corporation.

Haynes Stellite Company
A Division of
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General Offices and Works, Kokomo, Indiana
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Chicago — Cleveland — Detroit — Houston
Los Angeles — New York — San Francisco — Tulsa

LONG ISLAND COOLING PLANT

(*Continued from page 21*)

water, using 633 gal./min. of sea water at 70° F.

Three compressors are electrically driven one by a 2000-hp. motor and two each by 800-hp. motors. The latter two units are cooled by 208 sections arranged in 13 parallel stacks, 16 sections high. These sections cool 630 gal./min. of compressor jacket water from 113° to 90° F. using 550 gal./min. of sea water.

Jacket water for the two gas engines, circulated at 1400 gal./min., is cooled by 11 parallel stacks, 10 sections high. Sea water flows over these cooling sections at the rate of 420 gal./min. to lower the temperature from 162° to 150° F.

COMPETENT BOARD DEFENSE PERSONNEL URGED

Establishment of a competent board the level of the Secretary of Defense, composed of technically qualified people, both military and civilian, and having final authority for calling technically trained personnel to active duty, was urged as necessary to national safety, by Carey H. Brown, chairman, Engineering Manpower Commission, Engineers Joint Council in a letter to General George C. Marshall, Secretary of Defense, made public recently.

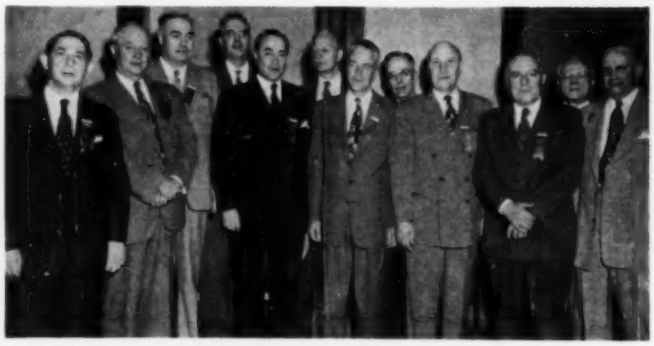
Grave consequences of dissipation and wasteful use of the nation's trained and skilled young men were pointed out by Mr. Brown as reasons for the Commission's recommendations.

PANEL ON CHEMICAL ENGINEERING PLANNED

A panel of chemical engineers from universities and industry will discuss the general topic, "Whither Chemical Engineering Science?" this December at the Atlantic City meeting of the A.I.Ch.E. according to plans just completed. The panel will be composed of, Prof. G. G. Brown, chairman, department chemical & metallurgical engineering, University of Michigan, as moderator, plus Prof. J. H. Rushton, director, department of chemical engineering, Illinois Institute of Technology, Prof. J. C. Elgin, assistant dean, school of engineering, Princeton University, Prof. R. L. Pigford, chairman, department of chemical engineering, University of Delaware, Dean T. K. Sherwood, dean of the college of engineering at M.I.T., and Karl H. Hachmuth, research planning board, Phillips Petroleum Co.

The panel is scheduled for Sunday afternoon, Dec. 2, 1951. At that time it will discuss underlying fundamentals of chemical engineering, and explain and explore new avenues of teaching unit operations and other chemical engineering subjects.

U.P.A.D.I. ORGANIZED AT HAVANA



Members of the engineering societies participating in Engineers Joint Council and the Engineering Institute of Canada who attended the Conference in Havana, April 19-22, 1951, at which a working Constitution and Bylaws for the next three years of UPADI (Pan American Union of Associations of Engineers) was approved and recommended for submission back to the parent societies: Left to right: S. S. Steinberg, A.S.C.E. (Advisor); J. M. Todd, president, E.J.C. (A.S.M.E.); J. Vance, president, Engineering Institute of Canada; W. N. Carey, executive secretary, A.S.C.E.; A. Ackerman, chairman, E.J.C. Delegation (Member, A.S.M.E., A.S.C.E., A.I.E.E.); L. Austin Wright, secretary, Engineering Institute of Canada; T. G. LeClair, president, A.I.E.E.; S. L. Tyler, secretary, A.I.Ch.E.; S. E. Reimel, secretary, Committee on International Relations of E.J.C. (A.S.M.E., A.S.C.E.); G. A. Hathaway, president, A.S.C.E.; F. Agthe, A.I.M.E., and W. Carson, A.I.M.E.

A preliminary draft of an international code of ethics was also prepared by the engineers representing 15 Pan American countries.

LOCAL SYMPOSIUM

(*Continued from page 20*)

pearance, confidence and poise, initiative and a true desire to sell were stressed as some of the necessary characteristics of a potential sales executive. A good general technical education, an acquaintance with the humanities, a grounding in business principles, a background of outside interests or hobbies, little or no experience in purely technical work, and six months to one year as a trainee constitute proper training for the potential sales manager.

Monsanto, Mr. Gillis added, develops its candidates through an Executive Development Program. This system includes annual interviews and merit rating, opportunity to move from job to job to obtain greater breadth of capacity, and leaves of absence for study of advanced management courses.

Dean T. K. Sherwood added to the afternoon's session by discussing the nature of the administrative function, the qualifications of good administrators, the current methods of training and selection and suggested procedures for both employer and engineer. Dr. Sherwood stated that management today must deal with complicated inter-relationships of multiple products, processes, and changing market situations as affected by technical developments in other industries. Thus, executives who have a background of science and engineering are well qualified to deal with the problems of industrial management.

Dr. Sherwood quoted a recent study by the Du Pont Company which showed that they paid more for psychological and personality qualities than for ability and knowledge qualifications. Thus, it can be seen, he said, that our universities and institutes must train men in cooperation, initiative, creativeness, judgment, leadership, ability to teach and supervise, rather than to increase the teaching of diverse technical courses.

Some steps that engineering schools take to provide the student with the business perspective necessary for management responsibility are, in Dr. Sherwood's opinion, the cooperative plan, practice schools, lectures by men from industry, night courses, electives in non-technical courses, and real experience in management through various student government activities.

The engineer with managerial aspirations can further his development, said Dr. Sherwood, by studying the company's finances, methods of determining costs, their patent position, the company's principal competitors, their advantages in the competitive market, and relations with the labor unions.

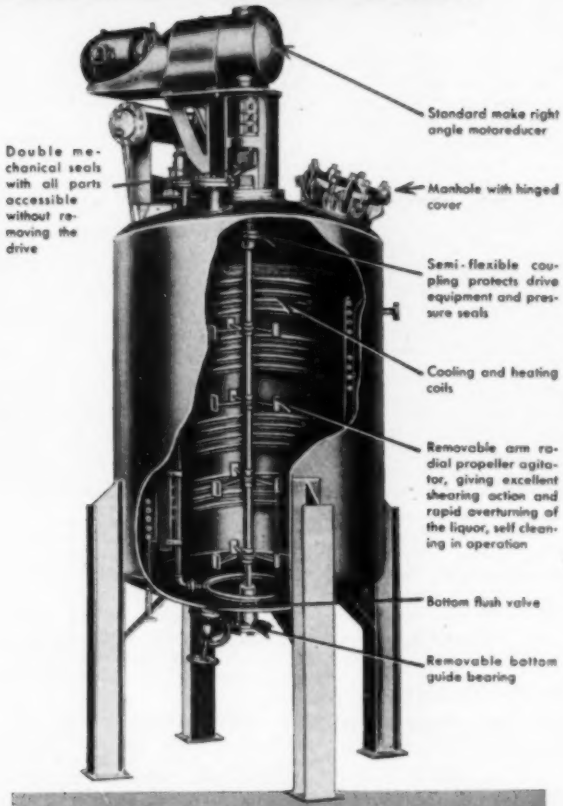
(*The End*)

NOW!

The Struthers Wells Hydrogenator

featuring

Advanced Agitator Design for Quick and Thorough Dispersion of Gases and Solids


Standard make right angle motoreducer
Double mechanical seals with all parts accessible without removing the drive
Manhole with hinged cover
Semi-flexible coupling protects drive equipment and pressure seals
Cooling and heating coils
Removable arm radial propeller agitator, giving excellent shearing action and rapid overturning of the liquor, self cleaning in operation
Bottom flush valve
Removable bottom guide bearing

The agitators, supporting structure, agitator shaft seals and drive incorporated in the new Struthers Wells Hydrogenator have been carefully designed to give maximum efficiency and long trouble-free service in dispersing gases and catalysts under normal or extreme conditions of temperature and pressure.

The diagrammatic illustration at the left shows how the agitator shaft is independently supported at two points within the vessel. Note how the radial propeller agitators are mounted in multiple on the shaft dividing the overturning of the content into several strata. The coils are carefully located to provide minimum obstruction to proper agitation and the flush outlet valve eliminates a pocket into which the catalyst might accumulate. This type of equipment is ordinarily made of stainless, nickel, monel, inconel or mild steel and individually designed to operate under specific conditions of pressure, vacuum, temperature and degree of agitation.

RADIAL PROPELLER AGITATOR

Because of its high peripheral blade speed and the rapid overturning and turbulent motion it imparts to the liquor, the radial propeller effectively disperses and entrains both the hydrogen and catalyst within the liquors to be treated thereby creating the optimum condition necessary to a maximum absorption and reaction. The removable arm feature provides inexpensive adjustment of the degree and type of agitation which might be necessary due to change of process or operating conditions.

Write for Complete Data

Struthers Wells

STRUTHERS WELLS CORPORATION

Process Equipment Division ... Warren, Pa.

PLANTS AT WARREN, PA. • TITUSVILLE, PA.

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LOCAL SECTION NEWS

PHILADELPHIA-WILMINGTON

At the regular meeting of this section held April 10 at the Clubhouse Hotel, Chester, Pa., the winners of the Zeisberg Memorial Award, who are students in chemical engineering at their respective schools, were announced as follows:

First prize—Lester E. DeBaun, Jr., Drexel Institute of Technology
Second prize—John B. Lambert, Princeton University
Third prize—John D. Potts, University of Pennsylvania

A. H. McKinney, chairman of the Zeisberg Award Committee presented the awards, which are technical books of the winners' own selection. These awards established by this section in 1941 are given for excellence in technical report writing to winners of a competition open to students in chemical engineering courses in the following schools: Bucknell, Drexel, Lehigh, Lafayette, Princeton, Delaware, Pennsylvania and Villanova. The award is offered in memory of the late Fred C. Zeisberg, Past President of A.I.Ch.E.

DeBaun, Jr., who served in the 106th Cavalry group in the European theatre during World War II, plans to go into production engineering or technical sales development work. Lambert, winner of the second prize, was employed last summer by Procter and Gamble Co., Dallas, Tex. His future plans include graduate study at the University of Wisconsin and subsequently design or process development work in industry.

Potts received his discharge from the Army in 1946 and was employed by U. S. Department of Agriculture in Eastern Regional Research Laboratory. During this, his senior year, he is working with Atlantic Refining Co. on plant design problem of portable natural gasoline unit.

The speaker for the evening was R. D. Morse, engineering research laboratory, Du Pont Experimental Station, Wilmington, whose subject covered Fluidized Solids Techniques. He reviewed their potentialities and limitations as applied to chemical processes other than petroleum cracking.

About 130 persons attended the meeting which was preceded by a dinner attended by approximately 85 people.

Reported by A. H. McKinney and William E. Osborn

TEXAS PANHANDLE

Thomas H. Chilton, President of A.I.Ch.E., addressed the April 12 dinner meeting of this Section which was held in Borger, Tex., and at which 80 or more members and guests were present. Dr. Chilton's talk titled, "Units—Scientific and Technical," was concerned with the functions of various societies, the purpose of which is to advance the profession of engineering. He went on to discuss the diminishing supply of engineers and the critical shortage which could very well occur at a time when the nation needs them most.

Reported by W. B. Polk

CENTRAL VIRGINIA

This Section's dinner meeting held at the Hotel General Wayne, Waynesboro, Va., April 6, 1951, was attended by 51 members and guests.

It was announced that L. E. Poese was appointed secretary-treasurer of the section.

John Larson of Fischer & Porter Co., Hatboro, Pa., gave a talk on "Predictable Metering Elements for the Flowrater Meter and their Effect upon the Specifications and Use of Flowrater Meters."

Reported by L. E. Poese

NEW YORK

Symposium—New Techniques and Devices for Process Engineering

The annual symposium of this section is now scheduled for Oct. 25 to be held at the Hotel New Yorker. It will be an all-day affair and will include a luncheon but not an evening meal. The general theme is "New Techniques and Devices for Process Engineering."

Though the speakers have not yet been designated the following papers are included in the preliminary program:

1. **Flotation Processing**—*Armour Co.*
2. **Pebble Heater**—*Babcock & Wilcox Co.*
3. **Hermetik Pump**—*Atlantic Pump Co.*
4. **Porous Metals**—*Micro Metallic Corp.*
5. **Air-cooled Exchangers**—*Trane Co.*
6. **New Ion-Exchange Applications**—*Rohm & Haas Co.*

The meeting on May 24 will feature H. J. Bowen, founder of the Industrial Models Co., Wilmington, Del., who will be the speaker at the annual business meeting.

Mr. Bowen's company has made models of chemical plants and oil refineries. It is hoped—though yet to be established—that future plants may be built with no formal piping drawings, but only isometric line drawings copied from the models, Mr. Bowen remarked.

The luncheon meeting on April 17 was held at the Brass Rail on Seventh Avenue. Speaker of the day was Chaplin Tyler, author of "Chemical Engineering Economics." Mr. Tyler is currently a management specialist in the development department of Du Pont Co.

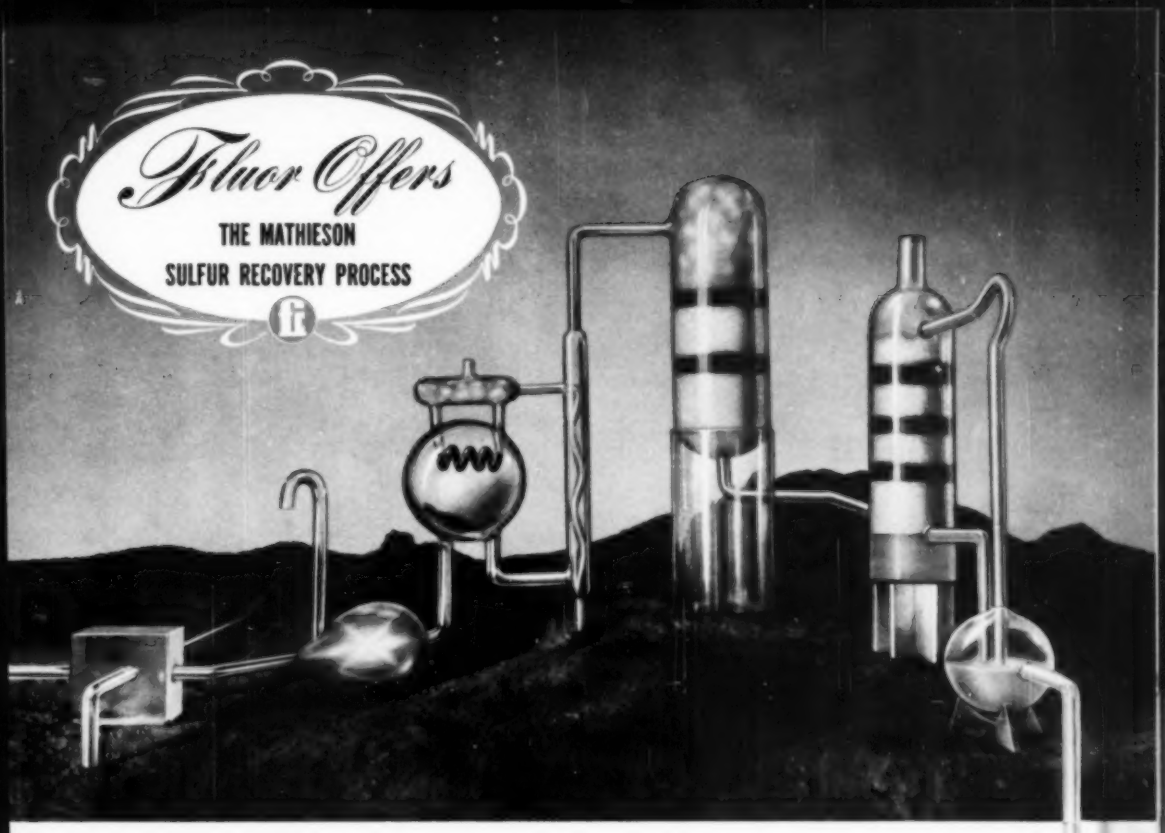
Mr. Tyler presented a guide to management that covers a wide range of subjects and is based on engineering evaluations. These guides come from unbiased studies covering many phases.

Reported by J. F. Skelly and L. C. Johnston

ZEISBERG CONTEST WINNERS

L. E. DE BAUN, JR. J. B. LAMBERT J. D. POTTS

(*More Local Section News on page 47*)



A simple process for the conversion of waste hydrogen sulfide to pure elemental sulfur

The availability of sulfur is rapidly becoming critical to the refining industry. First pinch was evident when sulfur and sulfuric acid were placed under allocation control by National Production Authority.

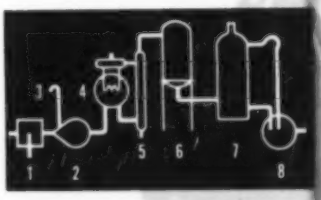
Primary cause of sulfur allocation is a gradual depletion of known deposits. Secondary cause is the great demand for sulfur in the manufacture of vital defense program materials. Mined sulfur is the normal source for such materials. The refiner, however, has in most cases his *own* potential source of sulfur.

Recovery from waste

The refiner's answer is the Mathieson Process for converting into sulfur the waste hydrogen sulfide recovered from sour petroleum gases. This simple process—available through The Fluor Corporation, Ltd.—accomplishes *two* important purposes:

1. *Guarantees independent supply* by affording each refiner an independent sulfur supply to meet his particular requirements—protection for the present, additional income for the future.

2. *Conserves for national defense* by contributing to the over-all National Defense Program in helping to conserve a critical commodity.



THE MATHIESON SULFUR RECOVERY PROCESS
Hydrogen sulfide, recovered from a sour gas stream, is partially burned with air—cooling follows with steam generated being utilized for power. Combustion gases are then passed through a catalyst tower to form sulfur and water vapor. Elemental sulfur product is condensed in a wash tower by direct contact with cooled liquid sulfur. The result is pure commercial sulfur—ready for sale or for conversion into sulfuric acid.

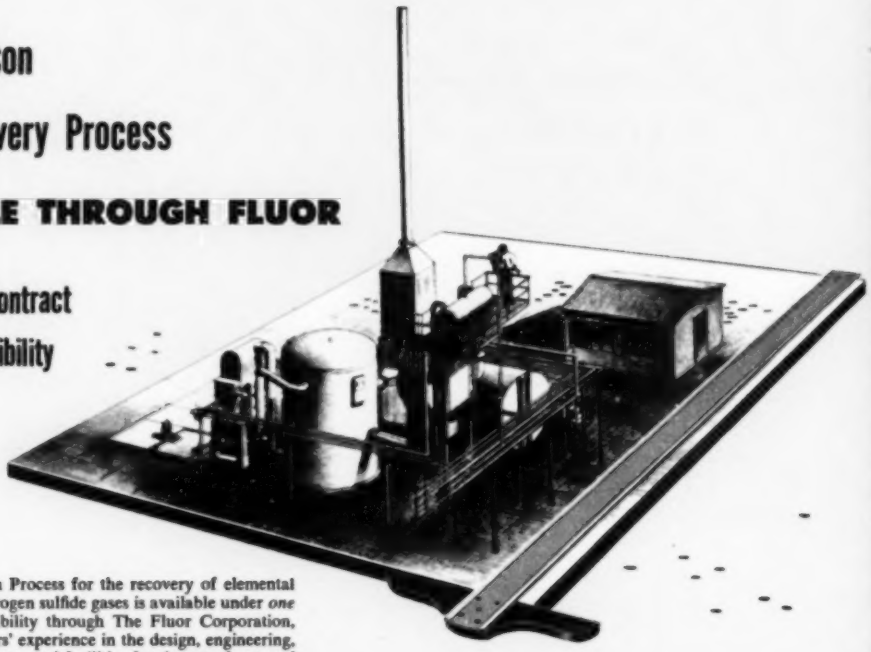
1—TREATING PLANT, 2—REACTOR FURNACE, 3—AIR INTAKE, 4—WASTE HEAT BOILER, 5—ECONOMIZER, 6—CATALYTIC CONVERTER, 7—SULFUR WASH TOWER, 8—RECIRCULATING SUMP

See Reverse Side

The Mathieson Sulfur Recovery Process

AVAILABLE THROUGH FLUOR

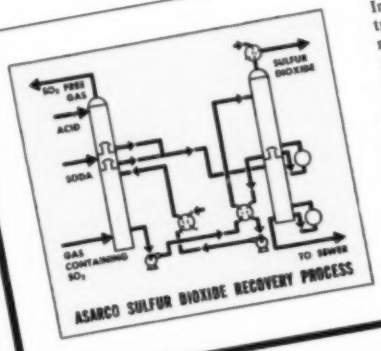
- Under ONE Contract
- ONE Responsibility



The proven Mathieson Process for the recovery of elemental sulfur from waste hydrogen sulfide gases is available under *one* contract, *one* responsibility through The Fluor Corporation, Ltd. With over 30 years' experience in the design, engineering, and construction of plants and facilities for the petroleum and chemical industries, Fluor possesses the background, the skilled personnel, and the know-how essential for the practical interpretation of the Mathieson Process into *your particular* sulfur recovery program.

Fluor is in a position to make economic studies covering every phase of proposed sulfur recovery installations—initial investment, operating costs, and returns to the investor.

A process for the recovery of Sulfur Dioxide is also available through FLUOR



ASARCO SULFUR DIOXIDE RECOVERY PROCESS

In line with Fluor's expanding activity in the fields of gas treating and sulfur recovery, arrangements have been made with the American Smelting and Refining Company (ASARCO) for Fluor to design, engineer and construct sulfur dioxide recovery plants using the ASARCO Process. Fluor's investigations have shown this process to be the most suitable of any available for the removal and recovery of pure sulfur dioxide from stack gases. In the application of the process, the gas is scrubbed with dimethylaniline which is then fed to a stripping column for sulfur dioxide recovery in a cyclic process. The resulting sulfur dioxide product may be dehydrated and liquefied for sale as liquid SO_2 or fed directly to an acid or sulfur plant.

All details including first studies are available through The Fluor Corporation, Ltd., and the American Smelting and Refining Company.

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New York, Chicago, Boston, Pittsburgh, Tulsa, Houston, San Francisco, Birmingham, Calgary.

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LOCAL SECTION NEWS

(*Continued from page 44*)

ST. LOUIS

This section held its meeting March 20 at the York Hotel. Seventy members and guests heard John J. O'Neill, Olin Industries, Inc., describe his company's research organization and the method

J. J. O'NEILL

which it uses to justify and evaluate industrial research. Mr. O'Neill pointed out that technical teams can use this method to sell their services to management and management can use it to measure the productivity of its staff.

Reported by A. T. Pickens

TIDEWATER VIRGINIA CHEMICAL ENGINEERS CLUB

This Club held its fifth program meeting March 30 at the Traveller Restaurant near Hopewell, Va. A. R. Bookout, research engineer with Hercules Powder Co., was guest speaker. More than 50 chemical engineers, members and guests attended the meeting.

Bookout, formerly a member of the general research group at Hercules Experiment Station near Wilmington, Del., spoke on "Equipment and Techniques for Research at High Pressures." The high pressure laboratory constructed by Hercules in 1947 was described, with emphasis on safety features included in design of building, equipment and controls.

Recently elected officers are:

President—W. C. Moser, Du Pont Co., Richmond, Va.
Vice-President and *Program Chairman:* W. P. Manley, Hercules Powder Co., Hopewell, Va.
Secretary—R. W. Nash, Du Pont Co., Richmond
Treasurer—E. Boehlig, Hercules Powder Co., Hopewell

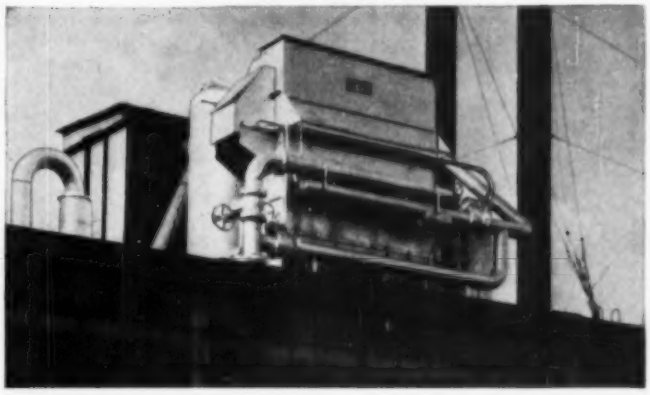
Reported by D. L. Burrell

COASTAL GEORGIA CHEMICAL ENGINEERS CLUB

At the March 15 meeting held at the Mary Calder Golf Club in Savannah, Ga., 58 persons heard T. H. Chilton give a talk on "Units—Technical and Scientific." Dr. Chilton is President, American Institute of Chemical Engineers.

Reported by E. O. Barnes

Direct saving of cooling water expense returns to you the cost of a Niagara Aero After Cooler in less than two years.



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It prevents many troubles and saves much expense

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Niagara Aero After Cooler uses evaporative cooling, saving 95% of your cooling water consumption. This saving quickly returns the cost of the equipment to the owner or makes extra cooling water available for other processes.

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Write for Bulletin 98

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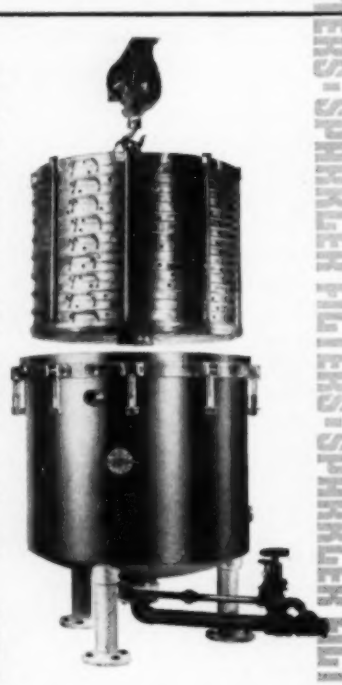

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WASHINGTON CHEMICAL ENGINEERS' CLUB

Symposium—New Processes for Critical Organic Chemicals

This section held a symposium April 23, 1951, in the Interior Department Auditorium, Washington, entitled, "New Processes for Critical Organic Chemicals." The symposium covered a discussion on some important new methods by which supply of organic chemical raw materials vital for military purposes and important in the civilian economy, can be increased.

The moderator of the symposium was L. C. Kemp of New York. Speakers and their subjects were as follows:

Aromatics by the Platforming Process—*Vladimir Haensel, Universal Oil Products Co., Chicago, Ill.*
Synthesis Via the OXO Reaction—*C. L. Levesque, Rohm and Haas Co., Philadelphia, Pa.*
Chemicals from Coal Hydrogenation—*W. C. Schroeder, U. S. Bureau of Mines, Washington, D. C.*

A dinner was held prior to the symposium at the Roger Smith Hotel at which 50 members and guests were present.

Reported by D. P. Herron

TWIN CITIES

The April dinner meeting of this Section was held at the Minneapolis Athletic Club, April 3. Thomas Chilton, President A.I.Ch.E., spoke on "Units, Physical and Professional." A large number of members, guests, and students from the A.I.Ch.E. Chapter at the University of Minnesota were present.

Reported by W. M. Podas

CHARLESTON, W. VA.

A general meeting of this Section was held at the Charleston Recreation Center March 20, 1951.

The speaker of the evening was Eric R. Braun, director of engineering, Merck and Co., who discussed "Chemical Engineering in the Medicinal and Drug Industry." He went into much detail on such things as chemical engineering manpower disposition, typical building layout, waste disposal, etc.

Reported by M. C. Guthrie, Jr.

OHIO VALLEY

A joint meeting with the Instrument Society of America was held recently at the Herman Schneider Foundation Building in Cincinnati. A talk on "Petroleum Refinery Operation" was given by the guest speaker R. J. S. Pigott, director of engineering, Gulf Research and Development Corp.

Reported by R. W. Evans

COLUMBIA VALLEY

Approximately 70 members and guests greeted T. H. Chilton, President of A.I.Ch.E. at a dinner meeting held at the Desert Inn Hotel in Richland, April 5. He gave a talk titled, "Units —Scientific and Technical." In substance Dr. Chilton upheld the engineering system of units as against the absolute or gravitational system. He stressed the importance of keeping units consistent. During the day R. H. Beaton and W. K. Woods escorted Dr. Chilton through Hanford Works installations.

Reported by Henry A. White, Jr.

OKLAHOMA

T. H. Chilton, President of A.I.Ch.E., and technical director, development engineering division, engineering department of Du Pont Co., discussed "Units—Scientific and Technical" at the April Meeting. Dr. Chilton stressed the need for a "common accepted" system of nomenclature for the various engineering units used in chemical engineering work. Approximately 75 members and guests were present.

Robert T. Sheen, president, Milton Roy Co., discussed "Automatic Control of Liquid Flow with Controlled Volume Pumps" at the March meeting.

Reported by B. L. Bates and H. W. Barber

FELLOWSHIPS IN INDUS. RES. BY UNIV. OF DENVER

Research Fellowships in chemical engineering will be awarded by the Institute of Industrial Research, University of Denver, according to George O. G. Löf, director. The stipend is $3,300 for 21 months starting Sept. 1, 1951. The recipients will work approximately 25 hr. per week in the Institute of Industrial Research while engaged in graduate study leading to the M.S. degree in chemical engineering.

LOCAL SECTION CALENDAR

COASTAL GEORGIA CHEMICAL ENGINEERS CLUB: *May 18, Brunswick, Ga. Speaker,* A. G. STANFORD, past president, National Society of Professional Engineers. Subject—"Registration for Chemical Engineers."

NEW YORK SECTION: *May 24, Brass Rail, 5th Ave. and 43rd St.* Annual meeting; election of officers. *June 12, Brass Rail.* Ladies' night. *Speaker,* J. C. BOUDREAU, Pratt Institute. Subject—"Art and the Chemist."

SOUTHERN CALIFORNIA SECTION: *June 19. Speaker,* W. B. SHANLEY, Universal Oil Products Co. Subject—"Platforming for the Production of Benzene."

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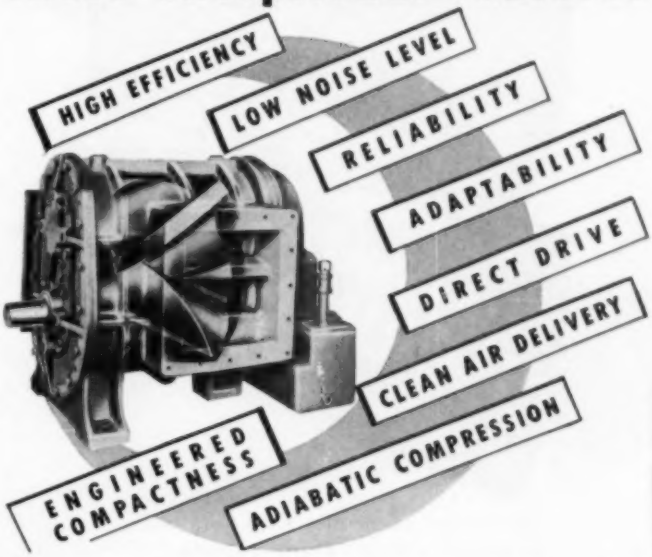

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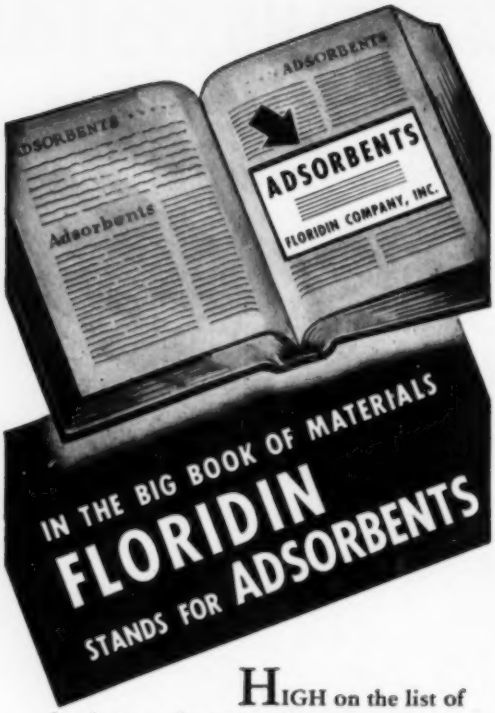

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DETROIT JUNIOR GROUP

This Section held a meeting April 4 1951, in the Junior Room of the Rackham Memorial. Leon S. Kowalczyk, assistant professor of chemical engineering at the University of Detroit, gave a talk entitled, "Education of Chemical Engineers in England." The speaker was educated in Poland and taught chemical engineering in both Poland and England before going to the University of Detroit.

In his discussion Dr. Kowalczyk compared the formal education of the chemical engineer in England with that of the chemical engineer in the United States. He said that chemical engineers in England can have any one of the three following backgrounds:

1. Formal university education in chemical engineering
2. College degree in a field other than chemical engineering and a year of postgraduate study in chemical engineering
3. Practical experience and an examination in chemical engineering fundamentals

Reported by W. W. Jones

BATON ROUGE

The third meeting of the year was held March 22 at the Heidelberg Hotel with 43 members and guests in attendance.

The guest speaker was Curry E. Ford of the National Carbon division, Union Carbon and Carbide Corp. who discussed "Recent Developments in Karbate Process Equipment." In his talk he covered improvements in design and installation techniques for pipe and fittings, improved pump seal construction, standardization of heat-transfer equipment, and design and performance of equipment for hydrochloric acid service.

Reported by J. C. Fedoruk

MARYLAND

This Section made an inspection trip to the Sparrows Point plant of the Bethlehem Steel Co., April 11. The tour began with lunch at the plant and demonstrated the entire steel-making process from coke manufacture through blast-furnace smelting, purification, hot and cold rolling to finished tin plate for can manufacture. Approximately 40 members and guests made the trip.

Reported by Alan Beerbower

CHICAGO

Col. V. C. Searle, of the U. S. Army Chemical Procurement, formerly of Gen. MacArthur's staff, was scheduled to talk about the rehabilitation of the Japanese chemical industry May 16.

Reported by Thorpe Dresser

(More Local Section News on page 52)

AN ENGINEER LOOKS AT UNESCO

(*Continued from page 30*)

is given them toward solving their most urgent problems.

Many peoples have had reason to dislike or suspect foreign developers of their resources. Yet they welcome engineering surveys and other technical assistance . . . . And some nations have invited and welcomed surveys intended to guide the investment of needed foreign capital. The more a proposed development is directly and obviously connected with the welfare of the people, and the better it is planned with social as well as economic understanding, the easier it is to enlist the local cooperation . . . . American engineers have had a part in many such foreign projects . . . .

7. A practical plan of collaboration between UNESCO and international engineering organizations was agreed upon at Paris, in March 1950, by the Engineers Advisory Committee to UNESCO. . . . .

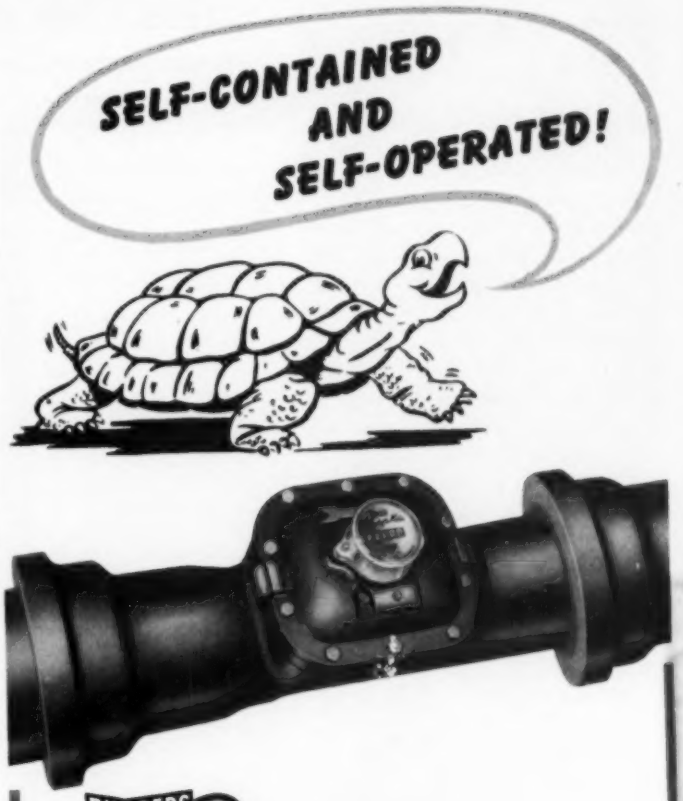
A constitution for a Union of International Engineering Organizations was adopted, with these stated "principal objects": (1) to coordinate the activities of the member organizations; (2) to make mutual arrangements for material and moral support; (3) to further relations with UN and its specialized agencies; and (4) to encourage the foundation of new engineering organizations in fields not already covered.

Fifteen international engineering organizations were invited to send delegates to an organization meeting which was held in Paris in September. . . . .

8. The Engineers Joint Council, representing the five United States societies of Chemical, Civil, Electrical, Mechanical and Mining Engineers, are dealing with engineering organizations in other American countries to form a Pan-American Union of Engineering Societies. . . . .

9. A conference on a plan related to the general subject, "How engineers Can Promote International Understanding," was held in New York in July between members of the Engineers Joint Council, other representatives of American engineering societies, and UNESCO representatives, including the head of the UNESCO Clearing House for Publications in Paris. It was agreed that the circulation abroad of the journals and the reports of transactions of American engineering societies is a definite influence toward international understanding . . . . Since UNESCO'S library bulletin has a world-wide circulation . . . . it was arranged that UNESCO will offer through this bulletin a list of these periodicals with subscription rates, and that subscriptions to any of them may be paid in UNESCO coupons. This plan . . . . has been submitted to the EJC and approved.

10. The Engineers Joint Council's International Relations Committee has now set up a Commission on Technical Assistance for the following primary purposes: (1) to establish and maintain liaison with such organizations as the Economic and Social Council and other UN agencies concerned with technical assistance . . . . and (2) to give direction to any other activities that the Engineers Joint Council may decide to undertake in the field of technical assistance. . . . . In these ways the engineering profession in the United States is being brought into a more intimate and we believe more potentially effective relationship with the whole program of technical assistance. . . . .



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FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Rochester, N. Y., Sheraton Hotel, Sept. 16-19. 1951.

Technical Program Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.

Annual — Atlantic City, N. J., Chalfonte-Haddon Hall Hotel, Dec. 2-5, 1951.

Technical Program Chairman: Frank J. Smith, Pan American Petroleum & Transport Co., 122 East 42nd St., New York 17, N. Y.

Atlanta, Ga., Feb. 17-20, 1952.

Technical Program Chairman: H. E. O'Connell, Ethyl Corp., Box 341, Baton Rouge, La.

French Lick, Ind., French Lick Springs Hotel, May 11-14, 1952.

Technical Program Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Chicago, Ill., Palmer House, Sept. 4-6, 1952.

Technical Program Chairman: George C. Lamb, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.

Technical Program Chairman: R. L. Savage, Dept. Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

SYMPOSIA

Maintenance
Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Rochester, N. Y.

Industrial Applications of Photography
Chairman: Carl Gath, Eastman Kodak Co., Kodak Park Works, Rochester, N. Y.
Meeting—Rochester, N. Y.

Round Table Discussion of Chemical Engineering Education
Chairman: W. E. Gift, Tennessee Eastman Corp., Kingsport, Tenn.
Meeting—Rochester, N. Y.

Opportunities in Sales for Chemical Engineers
Chairman: F. J. Curtis, Monsanto Chem. Co., 75 Rust Bldg., 1001 15th St. N.W., Washington 5, D.C.
Meeting—Atlantic City, N. J.

Chemical Engineering Fundamentals
Chairman: W. C. Edmister, Chem. Eng. Dept., Carnegie Inst. of Tech., Pittsburgh 13, Pa.
Meeting—Atlantic City, N. J.

Effective Speaking
Chairman: L. P. Scoville, Jefferson Chem. Co., 711 Fifth Ave., New York 22, N. Y.
Meeting—Atlantic City, N. J.

Vacuum Engineering
Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.
Meeting—French Lick, Ind.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

EL DORADO

"Fluid Catalytic Cracking" was the subject of a talk presented before 46 members and guests at the March 22 meeting of this Section, which was held at the Garrett Hotel, El Dorado, Ark. The guest speaker was T. J. Byrne, assistant technical director of Pan-Am Southern's El Dorado refinery.

Following a brief history of fluid catalytic cracking, Mr. Byrne, with the aid of slides, discussed the major process variables that determine cracking severity and yield structure.

Reported by R. L. Alexander

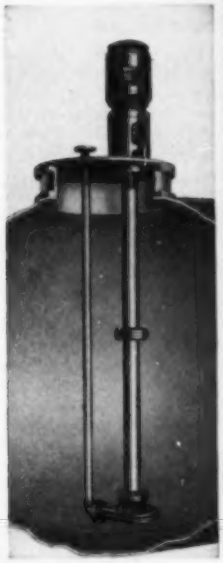
PEOPLE

Henry Howard, Past President of the American Institute of Chemical Engineers and an industrial chemist for many years, was awarded the 1951 Perkin Medal at the dinner meeting of the American section of the Society of Chemical Industry, which sponsors the award, held in the Astor Gallery Suite of the Hotel Waldorf-Astoria, New York, April 27, 1951. Long prominent in the chemical industry, Mr. Howard has been chairman of the executive committee of the Manufacturing Chemists' Association, and has been affiliated with Monsanto and Du Pont companies. Francis J. Curtis, 1949 President of A.I.Ch.E., delivered an address titled, "The Medalist and His Accomplishments." Mention of his being the recipient of this award was made in C.E.P., January, 1951, page 48.

Arno C. Fieldner, associated with the Bureau of Mines for more than 40 years, an inventor and developer of techniques for testing and analyzing coal, coke and gas, has been named chief fuels technologist. For many years Dr. Fieldner has been chief of the Bureau's fuels and explosives division. Joining the technologic branch of the Geological Survey in 1907 and moving to the Bureau of Mines when it was created in 1910 he became a member and subsequently was in charge of the Bureau's fuel chemistry laboratory. In 1919 he was made supervising chemist and later superintendent of the Bureau's Central Experiment Station at Pittsburgh. He has guided the Bureau's research and experimentation in the production of synthetic liquid fuels. In 1936 he became chief of the technologic branch directing work in mining, metallurgy, and fuels and explosives. In 1942 when the fuels and explosives service was created Dr. Fieldner became its chief.

Alfred L. Fuller, formerly chemical engineer with the Anaheim (Calif.) alkyd plant of the General Electric Co. is now research engineer with the Fluor Corp., Ltd., Los Angeles, Calif.

(Right) Structural details of Lawrence Vertical Chemical Pump.
(Below) Vertical Chemical Pump mounted inside of tank.



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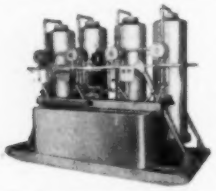

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Douglas A. Rogers has been appointed chemical engineer in the newly formed process equipment division of the Rodney Hunt Machine Co., Orange, Mass. This appointment is in line with the company's announcement of a new line of evaporators known as the Turba-Film evaporators; the manufacture and sales of these evaporators and related products for the food, chemical and pharmaceutical fields will be carried on through this new division. Mr. Rogers, who graduated from the University of Washington, was formerly supervisor of research for Lever Brothers.

John N. Mees is now in the capacity of sales engineer with the Safety Car Heating & Lighting Co., Inc. Formerly he was sales engineer with Dustex Corp., Buffalo, N. Y.

Stewart A. McHie, Jr., is now assistant superintendent of the National Refining Co. Previously he was shift superintendent of the Ashland Oil & Refining Co., Ashland, Ky.

Gordon Kiddoo has been appointed assistant director of the petrochemical research department of the National Research Corp., Cambridge, Mass. He will be in charge of the engineering economic aspects of the petrochemical research program which National Research is undertaking jointly with Electric Bond and Share Co. and United Gas Corp. Mr. Kiddoo received his degree in chemical engineering from Cornell University. Subsequently he was employed by Chicago Corp., near Bishop, Tex., and later was employed in the Olean (N.Y.) laboratories of Hydrocarbon Research, Inc. Prior to becoming director of research and development for Continental Carbon Co., Amarillo, Tex., late in 1949, he was associated with The Texas Co. in research and development work.

Ricardo Millares has been appointed technical director of Maiz Industrializadd, S.A. Mexico, D.F. Dr. Millares had been working with the Instituto Mexicano de Investigaciones Tecnológicas as a food technologist.

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JEFFERSON CHEMICAL CO. ELECTS VICE-PRESIDENTS

W. H. Bowman

Max Neuhaus

L. P. Scoville

W. H. Bowman, Max Neuhaus, and L. P. Scoville have been elected vice-presidents of Jefferson Chemical Co., Inc., New York, N. Y.

Dr. Neuhaus and Mr. Scoville have been on Jefferson's staff since the company was organized. Dr. Neuhaus, who went to Jefferson as manager of its technical and research department, had previously been with the Texas Co. and Texaco Development Corp. since 1932. He is currently serving on the Admissions Committee of A.I.Ch.E.

Mr. Scoville went to Jefferson in 1944 as chief engineer and was subsequently promoted to manager of the production department. Prior to his service with Jefferson, he was senior engineer for the Texas Co., which he served for 12 years. He is chairman of the commercial division of the Program Committee of A.I.Ch.E., and chairman of the New York Section of the Institute.

Dr. Bowman became Jefferson's market development manager in 1945, and when the company's sales department was organized, he was named manager of that department. He has been on the faculty of New York University, University of Toronto, and Case Institute of Technology. He has been affiliated also with Shawinigan Chemicals, Ltd., Armstrong Cork Co., and Westvaco Chlorine Products Corp.

CHANGES AT MONSANTO SPRINGFIELD PLANT

Men involved in a realignment of positions recently announced by the Monsanto Chemical Co., at Springfield, Mass., are as follows:

Allan W. Low has been appointed division engineer of the plastics division at Springfield. In his new capacity he succeeds C. O. Hoyer, who has accepted the position of chief engineer with The Chemstrand Corp., a jointly owned subsidiary of Monsanto and American Viscose Corp. Simultaneously the promotions of C. D. Smith and F. E. Reese to assistant division engineers and of A. W. Andrews to chief project engineer were announced.

Mr. Low has been affiliated with Monsanto since 1948. Prior to that time he was employed by the general chemical division of Allied Chemical and Dye Corp. He attended the University of New Hampshire where he received a B.S. degree in 1936.

Mr. Smith will be responsible for the activities of the project and design group of divisional engineering. He has been with Monsanto since 1939 and has served in the research, production and engineering departments of the plastics division. Mr. Smith attended Purdue University, where he received a B.S. degree in 1937 and an M.S. in 1939.

Mr. Reese, who will be responsible for the development and planning groups of division engineering, joined Monsanto in 1941, shortly after graduation from Purdue University with a B.S. degree. He has worked in both the research and engineering departments of the division.

Mr. Andrews will have responsibility for the project group of the division's engineering department. With Monsanto since 1940 he was employed by the company's Texas division prior to joining the plastics division. Mr. Andrews attended Yale University where he received a B.S: degree.

M. W. Plunkett is now nitrocellulose superintendent at the Hercules Powder Co., Radford Arsenal, Radford, Va. He was formerly at the company's Parlin (N.J.) plant.

Robert W. Ritzmann recently accepted a position as process engineer with the Koppers Co., chemical division, at its Kobuta plant, Monaca, Pa. He was formerly employed as a chemical engineer by the Standard Oil Co. (Ind.)

Max A. Turner is now a chemical engineer at the chemical power branch of the underwater ordnance, Department U. S. Naval Ordnance Test Station, Pasadena, Calif.

David J. Jay, now an instructor in the chemical engineering department, University of Detroit, Detroit, Mich., was formerly an engineer with Jay-Mark Products Co., Detroit.

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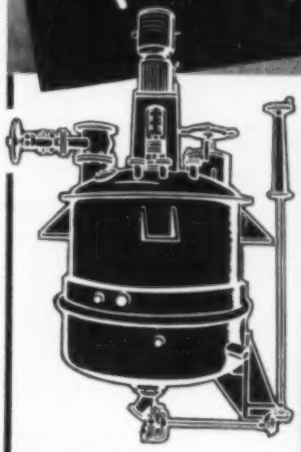

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Albert Victor Bleininger Award of 1950, the highest honor conferred in the field of ceramics, being presented to John C. Hostetter at the Hotel Schenley, Pittsburgh, Pa., March 16. Left to right: R. E. Birch, chairman, Bleininger Award Committee; J. C. Hostetter, medalist; H. R. Lillie, president-elect, American Ceramic Society, and F. P. Shonkwiler, chairman, Pittsburgh Section of the Society. Dr. Hostetter, recently retired, was president of the Mississippi Glass Co.

Victor E. Wellman has been named director of process engineering department according to an announcement by S. C. Moody, general manager, Calco chemical division, and vice-president of American Cyanamid Co. In his new capacity, Wellman will direct process development and chemical engineering activities which have been merged to form the process engineering department.

Dr. Wellman obtained his A.B. from Phillips University, Enid, Okla., in 1924, and his M.S. (1927) and Ph.D. (1929) from the University of Washington.

He was associated with B. F. Goodrich Co. for 15 years as director of purchases, chemicals division, and later with R. W. Greeff Co. as assistant sales manager, solvents department. In 1945, he joined Calco and since 1949 has been associate director of process development.

Alden R. Loosli, assistant manager, intermediate and rubber chemicals department, American Cyanamid Co., Calco chemical division, is attending the Advanced Management Program of the Harvard Graduate School of Business Administration. The program, now in its twentieth session, is an intensive three months' course of study for business executives.

Arthur G. Kracker has been appointed a development engineer of the Buffalo Electrochemical Co., Buffalo, N. Y. He was formerly a development engineer in the Central Electrotype Co., Cleveland, Ohio.

Morrison W. Brinker is now serving as purchasing engineer with the Stearns-Roger Manufacturing Co., Denver, Col. Formerly he was engineer at the Gates Rubber Co., Denver, Col.

Frederick A. Richter is now serving the Blaw-Knox Co., Pittsburgh, Pa. He is in the chemical plants division as a chemical engineer. He was formerly with Lederle laboratories division of the American Cyanamid Co., in Pearl River, N. Y.

Sanjeev Ananda Rao, formerly refinery engineer with the Ohio Oil Co., Robinson, Ill., is now process engineer with The Assam Oil Co., Digboi, Upper Assam, India.

Walter F. Ratcliff is a chemical engineer with the Lago Oil & Transport Co., in Aruba, Netherlands West Indies. He was previously a chemical engineer at the Esso laboratories Standard Oil Co. of New Jersey.

Herbert A. Rainbird is now junior process engineer with the Magnolia Petroleum Co., Beaumont, Tex. He previously was engineering aide to the Socony Vacuum Oil Co., New York, N. Y.

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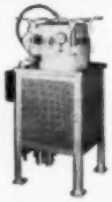

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Robert E. Workman was recently named manager of the newly established district office of the Goodyear Tire & Rubber Co. at St. Louis. Prior to this, Mr. Workman had been serving accounts in the St. Louis area as a field representative. He started service with Goodyear in 1942, following his graduation from Case School of Applied Science, Cleveland. After extensive service in the company's research laboratory, he was assigned to the chemical division, and was sent to St. Louis as a field representative in 1948.

FREEMAN, CONSULTANT COAL CARBONIZATION

John V. Freeman, who recently retired as director of the coal chemical sales division, U. S. Steel Co., after 43 years association in the iron and steel industry, established an office, Suite 3459, at 45 Rockefeller Plaza, New York 20, N. Y., effective April 16, 1951. There he will maintain a consultant organization devoted to the technological phases of carbonization of coal and coal chemicals. Mr. Freeman's entire career has been devoted to specialization in the chemistry of coal and coal carbonization.

His early experience as chief chemist of the Central Coal Research Laboratory of the Illinois Steel Co. saw him active with the construction of the first modern by-product coke ovens in America at Joliet, Ill., in 1908. During World War II Mr. Freeman was a member of the Coal Tar and Nitrogen Advisory Committee.

George J. Haddad, fellow at Mellon Institute, Pittsburgh, Pa., was recently appointed senior fellow of the multiple fellowship on nitrogen compounds sustained by the U. S. Steel Co. Mr. Haddad holds an M.S. degree in chemical engineering from the University of Pittsburgh and is a registered professional engineer in Pennsylvania. Before joining the U. S. Steel Co.'s fellowship in 1946 he worked on the synthetic rubber program sponsored by the U. S. Government at Mellon Institute.

T. L. Gore is now with the Standard Oil Co. (Ind.) located in Sugar Creek, Mo. He is serving in the capacity of chemical engineer, technical service group. Previously he was a graduate student at the University of Kansas, Lawrence, Kan.

(*More About People on page 59*)

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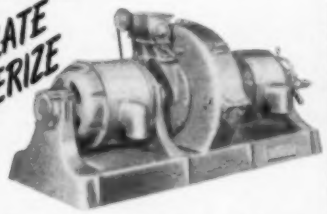

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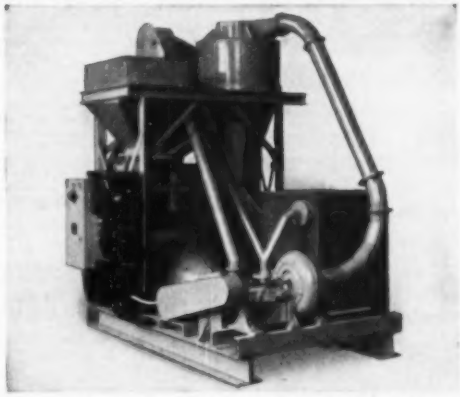

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Wanted—Chemical engineers and chemists for production and pilot plant. Reply to Kentucky Synthetic Rubber Corp., P. O. Box 360, Louisville, Ky., stating education, experience, salary requirements.

PROJECT ENGINEERING — Chemical and mechanical engineers with one to five years' experience in project engineering for permanent addition to Engineering Division Staff. Indiana location. Housing not critical. Give details of training and experience. Commercial Solvents Corporation, Terre Haute, Indiana. Attention: Odon S. Knight.

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Executive Chemical Engineer—B.S., age 40, family. Registered professional engineer by examination. Experienced in design, engineering, construction, operation, and management of chemical plants. Desire heavy administrative responsibilities in chemical industry. Box 5-5.

(Continued on page 59)

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Chemical Engineer—S.M. M.I.T., 1948; 27, married, Tau Beta Pi, Sigma Xi, publications. Located in the Philippines. Three years management and production work. Highest recommendations. Spanish citizen, good knowledge of Spanish and Filipino life and handling local labor. Desire production work with American concern in the Philippines, Spain or South America. Box 8-5.

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Part Time; Summer Employment—for chemical engineer, Ph.D., P.E. Eleven years industrial and teaching. Member of New York College Faculty. Box 10-5.

PEOPLE

(Continued from page 57)

William R. Seuren, formerly assistant to W. J. Carthaus, vice-president in charge of Deep Rock Oil Corp.'s manufacturing and research division, has been named supervisor of lubricating oil finishing at the company's Cushing (Okla.) refinery. Mr. Seuren went to Deep Rock in 1949 and after receiving his Master's degree in business administration from Harvard University. He obtained his B.S. degree in chemical engineering from Pennsylvania State College and his M.S. in chemical engineering from Massachusetts Institute of Technology. Before going to Harvard in 1947, Mr. Seuren worked as process engineer with Foster Wheeler Corp., E. B. Badger & Sons, and Stanolind Oil & Gas Co.

Lowell L. Fellinger has been appointed coordinator of technical personnel procurement for Monsanto Chemical Co.'s organic chemicals division. **Robert E. Howard** will succeed Dr. Fellinger as assistant director of research in charge of the pilot plant and interim production facilities. Dr. Fellinger will continue as assistant director of the research department but will devote full time to the problems of locating and employing technical manpower for the organic chemicals division. Dr. Fellinger joined the organic chemicals division in 1941 as a research chemist and in 1944 was named pilot plant group leader. His appointment as the division's assistant director of research was announced in 1947. Dr. Howard joined Monsanto in 1943 as a research chemist.

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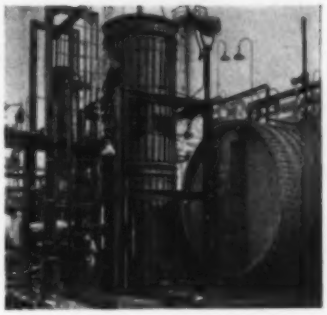

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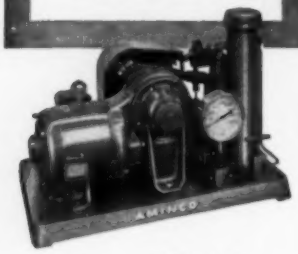

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PEOPLE

(*Continued from page 59*)

Ralph M. Hunter of The Dow Chemical Co. was elected president of the Electrochemical Society effective April 12. The new president has been a member of the society since 1922 and was its vice-president for the past three years.

Dr. Hunter received the B.S. degree in chemical engineering from Case Institute of Technology in 1918 and an honorary degree of doctor of engineering in 1950. He became associated with The Dow Chemical Co. in 1918 and now manages its electrochemical division, is director and president of the Midland Ammonia Co. and director of Dow Chemical of Canada, Ltd.

At present he is on the board of directors of the Chlorine Institute.

William C. McConnell has been appointed operating engineer of the Girdler Corp., Louisville, Ky. Prior to that he was chemical engineer with the National Carbide Corp., Louisville, Ky.

Robert A. Louis has been named production engineer with Merck & Co., Rahway, N. J. He was formerly assistant research director, Smith-New York Co., Freeport, N. Y.

Frank C. Fowler, formerly of the University of Oklahoma faculty, has been added to the staff of Midwest Research Institute, Kansas City, as petroleum consultant. He will conduct investigations in petroleum and allied fields for the Institute. This activity has been initiated as a result of numerous industrial requests for assistance in this field.

Fowler attended the universities of Illinois and Michigan, and was awarded the Ph.D. degree from the latter school in 1943. From 1943 to 1946, he was senior process engineer in the chemical products department at Phillips Petroleum Co., Bartlesville, Okla. At the university since 1946, he administered both graduate and undergraduate courses, and directed graduate research. He also conducted industrial research programs for the University of Oklahoma Research Institute.

Julian B. Willis, is now serving the Sinclair Rubber, Inc., in Houston, Tex., as chemical engineer. He was previously process design engineer with the Sinclair Refining Co., Harvey, Ill.

Van A. Wente is now a chemical engineer with the Naval Research Laboratory, Washington 20, D. C. He was formerly associated with Firestone Plastics Co., Pottstown, Pa., as chemical engineer.

Raymond B. Thrower, formerly sales engineer with Griscom-Russell Co., Houston, Tex., is now chemical engineer with the Goodyear Tire & Rubber Co., Akron, Ohio.

KEYES WITH N.A.M. IN ADVISORY CAPACITY

Donald Babcock Keyes, special consultant to the Heyden Chemical Corp., New York, has joined the staff of the National Association of Manufacturers in an advisory capacity to the association's Committee on Research.

Dr. Keyes served as a vice-president of Heyden Chemical for the five years ending last December, when he was made special consultant.

From 1926 to 1945 he was professor of chemical engineering and head of the chemical engineering division at the University of Illinois. However, from 1941 to 1945 he was absent on leave in Washington, D. C., with various war agencies.

G. G. BROWN, DEAN OF ENGINEERING

George Granger Brown, on the faculty of the University of Michigan, Ann Arbor, Mich., since 1920, and more recently director, U. S. Atomic Energy Commission's division of engineering, has been appointed dean of the College of Engineering, University of Michigan. The new dean of engineering was President of the American Institute of Chemical Engineers in 1944 and in 1939 received its Walker Award. Currently he is chairman of the A.I.Ch.E. Chemical Engineering Education and Accrediting Committee. He served as Director of A.I.Ch.E. in 1940-42.

Necrology

A. R. FRANCK

Albert R. Franck, chemical engineer of the Celanese Corporation of America, Cumberland, Md., died recently. Graduated from the University of Pittsburgh with a B.S. in chemical engineering, he was 40 years old. He served also the Canadian Celanese, Ltd., and for three years was with the U. S. Army ordnance department.

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BUBBLE CAP BULLETIN 21

Largest Compilation of Engineering Data.

Lists 200 Styles Furnished Without Die Cost.

This standard reference contains complete specification information for over 200 standard styles of bubble caps and risers. Also drawings for use in determining methods of tray assembly. All styles listed in Bulletin 21 are furnished promptly, without die cost, and in any alloy to meet your coking or corrosion problems. Special caps gladly designed; write us to your needs.

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CROLL-REYNOLDS CO., INC.

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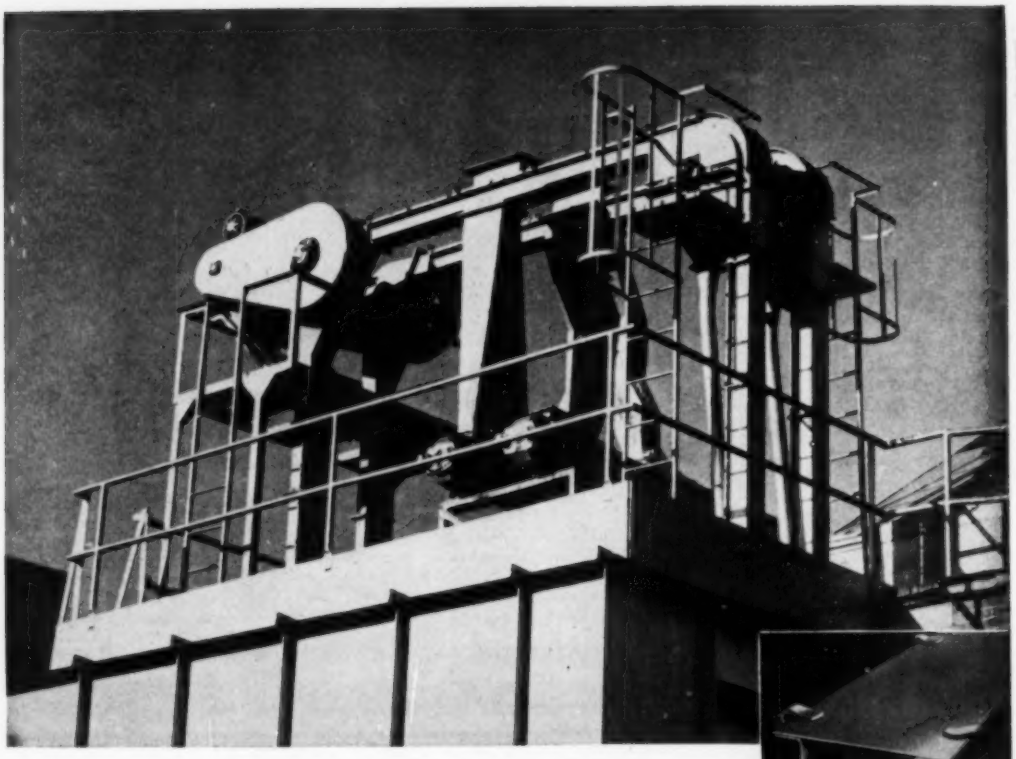

Protecting Fine Materials from Hopper to Storage...

NO CONTAMINATION! NO SPILLAGE! NO ESCAPE! WITH REDLER CONVEYORS AND ELEVATORS!

Merck & Company, Inc., manufacturing chemists, required handling equipment to protect materials against contamination, to prevent loss by spillage and to guard against escape of materials into the atmosphere. S-A engineers designed and installed the simple, compact, space-saving REDLER Conveyor-elevator system pictured above, two-thirds of which is out-of-doors. It successfully meets every requirement—operates efficiently and economically, day-in and day-out! . . . If you have a material handling problem—if your equipment is less than demanded by today's high production, you will do well to draw upon the 50 years of practical, specialized experience available to you through the S-A engineering and manufacturing service. Write today, without obligation for complete information.

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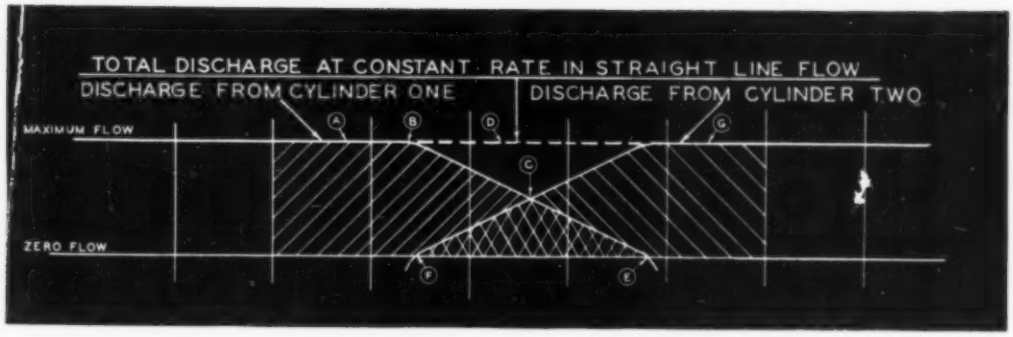
MERCK & CO. Inc. (Stonewall Plant)
ELKTON, VIRGINIA

Two different raw materials are dumped into double loading hoppers on the first floor of the building. Two vertical, closed-circuit REDLER elevators with short 10-foot long, horizontal feed sections of casing under each hopper pick up materials and elevate them about 56 feet thru the roof of the building to a point where materials are transferred to two horizontal REDLER conveyors. One of the horizontal conveyors is 36 feet long and the other is 45 feet long. The horizontal REDLERS extend over large storage bins and discharge materials thru gate controlled chutes to storage. Upper half of elevators and all of horizontal conveyors are out-of-doors and weather-tight REDLER construction is a big advantage in protecting materials. REDLERS include the following advantages: (1) dust-tight and weather-tight casings protect materials and prevent loss, (2) compact design permits simple, space-saving installation.

DESIGNERS AND MANUFACTURERS OF ALL TYPES OF BULK MATERIALS HANDLING EQUIPMENT



"Constametric" pump discharge curves. Showing how two reciprocating plungers deliver at a constant rate of flow.

A—Plunger number one discharges into manifold at maximum flow and constant rate.
B—Plunger one at start of deceleration.
C—Crossover point where discharge by plunger one equals discharge by plunger number two.
D—Combined discharge by plunger one and plunger two. Note the continuation of constant flow.
E—End of discharge stroke and start of suction stroke, plunger one.
F—Plunger two at completion of suction stroke and start of discharge stroke.
G—Plunger two discharging into manifold at maximum flow and constant rate.

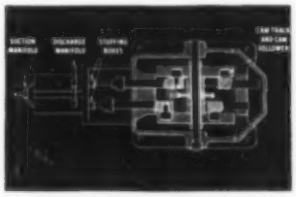
The Controlled Volume Pump that Delivers in Straight Line Flow

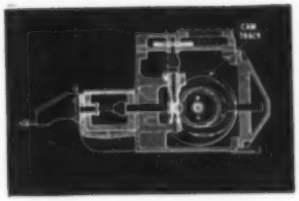
The Milton Roy "Constametric" is a positive displacement, controlled volume chemical pump having a constant flow delivery without pulsation. Two double-ball check liquid ends are employed. The plungers are driven by cams so designed that the speed of one plunger decelerates at the end of its stroke at a rate equivalent to that at which the second plunger accelerates. Since the two liquid ends have common input and output manifolds, the combined delivery of the plungers is at a constant rate of flow at the cross-over point between plunger loadings, as well as during the balance of each plunger stroke. The pumping action is exactly the same as that of a single plunger, moving forward continuously at a fixed rate of speed.

Capacities and Pressures

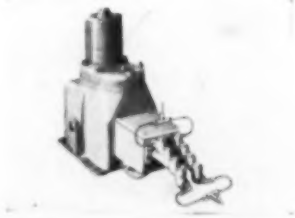
"Constametric" pumps are furnished with plungers from 3/16" to 1 1/16" dia., to pump from a minimum of 0.07 gallons (250 ml) per hour to a maximum of 57 gallons per hour. Maximum pressures range to 5,000 psi, on the smallest plunger diameter. Automatic, stepless speed regulation over a range of 20 to 1 is obtained by means of the Thymotrol electronic system. Any metered variable, such as flow, temperature, conductivity, pressure, etc., can be utilized to actuate the speed of the pump through this electronic control system, thus regulating the metered rate of discharge.

For typical delivery curves, capacity-pressure table, applications and engineering data, ask for Bulletin 649.





Showing drive mechanism, cam track, cam follower, etc. Milton Roy "Constametric" Pump. Principles of design and application fully covered by patent applications.



MILTON Koy COMPANY

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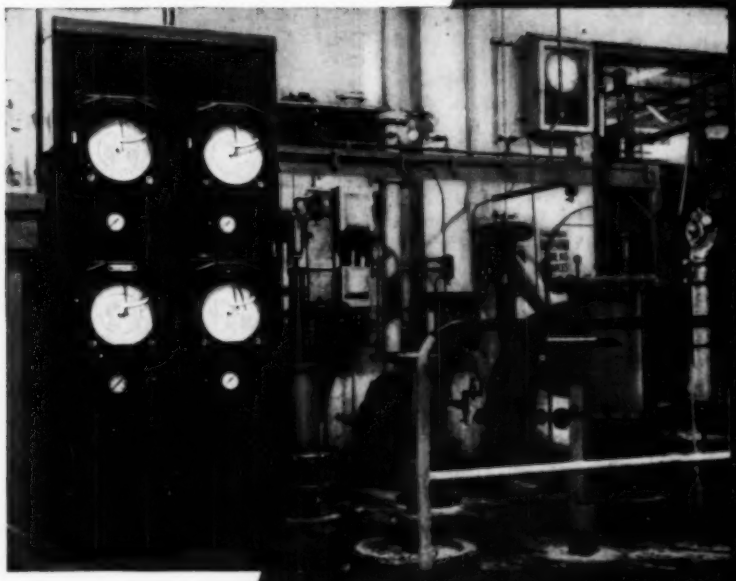

A panel of three F&P Ratio-Controllers blending wood pulp slurry with one additional recording-controller. Also shown are large-capacity RATOSLEEVE flow meters and control valves.

● WIDE RANGE OF APPLICATION

A choice of F&P primary elements is available to handle a range of flows as low as 4-40 cc/min liquid for pilot plant blending or treating-reagent additions to any measurable high capacity flow in closed or open channels.

● WIDE RANGE OF MEASUREMENT

The wide-range linear flow scales of F&P primary elements permit outstanding rangeability of flows under all conditions—not merely at or near design ratio.

● WIDE RANGE OF SETTING

Controlled flow can be in any desired ratio to "wild" or uncontrolled flow. Ratio selector scales are graduated from 15% to 600% (scale length is 7"). Pneumatic-set ratio is available for applications such as pH control. Vernier adjustment can be supplied for extreme precision of setting.

● COMPLETE RATIO-CONTROL SYSTEM

Full responsibility for the proper coordination and smooth performance of the various components of the system is vested in Fischer & Porter, manufacturer of the primary elements (FLOWRATOR meters, V/A Cell Kinetic manometers, and others)—secondary elements (RATOMATIC control instruments) — and VALVRATOR control valves.

PROCESS CONTROL INSTRUMENTS

FLOWRATOR

FISCHER & PORTER COMPAN

HATBORO, PENNSYLVANIA, U.S.

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